

**Bacteria Total Maximum Daily Load (TMDL)  
Development for the Mattaponi River and  
Tributaries Located in Caroline, Essex, King  
William, and King and Queen Counties, Virginia**

## Table of Contents

EXECUTIVE SUMMARY .....	xxi
Applicable Water Quality Standards .....	xxi
Description of Project Area .....	xxv
Pollutant Sources .....	xxv
TMDL Technical Approach .....	xxv
TMDL Endpoints.....	xxvi
TMDL Description and Calculations .....	xxvi
TMDL Implementation/Reasonable Assurance .....	xxviii
Public Participation.....	xxix
1 INTRODUCTION.....	1
1.1 Regulatory and Guidance Basis .....	1
1.2 Applicable Water Quality Standards.....	2
1.2.1 Designated Uses.....	3
1.3 TMDL Endpoints .....	3
1.3.1 Study Area Description & List of impairments .....	4
1.3.2 Aylett Creek (F23R-04-BAC).....	4
1.3.3 Courthouse Creek (F24R-03-BAC).....	5
1.3.4 Dickey's Swamp (F23R-08-BAC).....	5
1.3.5 Dogwood Fork (F23R-11-BAC).....	5
1.3.6 Dorrell Creek (F21R-08-BAC).....	6
1.3.7 Garnetts Creek (F23R-01-BAC).....	6
1.3.8 Gravel Run (F21R-09-BAC).....	6
1.3.9 Herring Creek (F21R-05-BAC) .....	6
1.3.10 Market Swamp (F23R-09-BAC).....	7

1.3.11	Mattaponi River (F21R-06-BAC) (Non-tidal).....	7
1.3.12	Mattaponi River (F23E-02-BAC and F24E-02-BAC) (Tidal) .....	7
1.3.13	XDN–Garnetts Creek, UT (F23R-12-BAC) .....	8
1.3.14	XJG–Dickeys Swamp, UT (F23R-10-BAC) .....	8
2	WATERSHED CHARACTERIZATION .....	12
2.1	Selection of Subwatersheds.....	12
2.2	Water Resources, Ecoregion, Soils, and Climate.....	14
2.2.1	Water Resources .....	14
2.2.2	Ecoregion .....	15
2.2.3	Soils.....	15
2.2.4	Climate.....	20
2.3	Land Use .....	22
2.4	Stream Flow Data.....	26
2.5	Water Quality Monitoring Data .....	27
3	POLLUTANT SOURCES.....	31
3.1	Permitted Point Sources .....	31
3.1.1	VPDES Permits.....	31
3.1.2	MS4 Permits.....	34
3.1.3	Biosolids .....	34
3.1.4	Animal Feeding Operations .....	35
3.2	Nonpoint Sources .....	35
3.2.1	Septic Systems and Straight Pipes and Pit Privies.....	35
3.2.2	Pets .....	39
3.2.3	Livestock.....	39
3.2.4	Wildlife .....	42

4	MODELING APPROACH.....	44
4.1	Modeling Goals, Considerations and Assumptions .....	44
4.2	Modeling Software - HSPF (EFDC discussed in Section 6).....	45
4.2.1	Boundary Conditions .....	46
4.2.2	Simulation Period.....	46
4.3	Development of the Project Area Model.....	47
4.3.1	Initial Model Setup .....	48
4.3.2	Watershed Data Management (WDM) Preparation.....	54
4.3.3	Hydrologic Calibration .....	54
4.3.4	Water Quality Model Setup .....	59
4.3.5	Fecal Coliform Die-off Rates.....	62
4.3.6	Water Quality Calibration and Validation .....	63
5	TMDL BACTERIA ALLOCATION .....	65
5.1	Consideration of Seasonal Variations and Critical Conditions.....	66
5.2	Incorporation of Margin of Safety (MOS) .....	66
5.3	Wasteload Allocation Development.....	67
5.4	Load Allocation Development .....	67
5.5	Summary of Non-Tidal TMDLs .....	68
5.5.1	Aylett Creek (VAP-F23R_AYL01A12).....	68
5.5.2	Courthouse Creek (VAP-F24R_CTH01A00).....	73
5.5.3	Dickeys Swamp (VAP-F23R_DKW01B00) .....	78
5.5.4	Dogwood Fork (VAP-F23R_DWD01A00).....	83
5.5.5	Dorrell Creek (VAN-F21R_DRL01A18).....	88
5.5.6	Garnetts Creek (VAP-F23R_GNT01A00) .....	93
5.5.7	Gravel Run (VAN-F21R_GVL01A18) .....	98

5.5.8	Herring Creek (VAN-F21R_HER01B02; VAN-F21R_HER01A06) .....	104
5.5.9	Market Swamp (VAP-F23R_MKT01B00).....	110
5.5.10	Mattaponi River (non-tidal) (VAN-F21R_MPN01C02; VAN-F21R_MPN01B02) 116	
5.5.11	XDN-Garnetts Creek, UT (VAP-F23R_XDN01A00).....	122
5.5.12	XJG-Dickeys Swamp, UT (VAP-F23R_XJG01A14) .....	128
5.6	The Final Total Maximum Daily Loads.....	135
6	3D MODEL DEVELOPMENT AND TMDL ALLOCATION (TIDAL) .....	137
6.1	Description of the EFDC Model .....	137
6.2	Model Setup .....	138
6.3	Model Calibration of Salinity.....	141
6.4	Model Calibration of Bacteria.....	143
6.5	Model Simulation of TMDL .....	145
7	IMPLEMENTATION AND REASONABLE ASSURANCES .....	149
7.1	Continuing Planning Process and Water Quality Management Planning.....	149
7.2	Implementation of Waste Load Allocations and Reasonable Assurances .....	150
7.2.1	Stormwater Permits.....	150
7.2.2	Existing Non-Stormwater VPDES Permits .....	150
7.2.3	TMDL Modifications for New or Expanding Discharges .....	151
7.3	Implementation of Load Allocation and Reasonable Assurance .....	151
7.3.1	Implementation of Load Allocations .....	151
7.3.2	Implementation Plan Development.....	152
7.3.3	Staged Implementation Scenarios.....	152
7.3.4	Link to Ongoing Restoration Efforts .....	153
7.3.5	Implementation Funding Sources .....	153

7.3.6	Follow-Up Monitoring.....	154
7.4	Attainability of Designated Uses.....	155
8	PUBLIC PARTICIPATION.....	158
9	REFERENCES .....	160
	Appendix A: Glossary.....	166
	Appendix B: Inventory of data and information used in TMDL development .....	175
	Appendix C: Time Series Plots for Water Quality Calibration and Validation.....	176
	Appendix D: HSPF Model Sensitivity Analysis.....	185
	Hydrology Sensitivity Analysis .....	185
	Water Quality Parameter Sensitivity Analysis .....	187

## List of Tables

Table ES-1. Summary of Stream Segments impaired for E. coli in the project area (based on the 2016, 2018, and 2020 305(b)/303(d) Water Quality Assessment Integrated Report) .....	xxiii
Table ES-2. Annual TMDL (counts/year) for E. coli bacteria in the non-tidal impairments within the project area. The TMDLs include future growth in the WLAs .....	xxvii
Table ES- 3. Daily TMDL (counts/day) for E. coli bacteria in the non-tidal impairments within the project area. The TMDLs include future growth in the WLAs .....	xxviii
Table ES-4. Annual TMDL (counts/year) for E. coli bacteria in the tidal impairments within the project area. The TMDL includes future growth in the WLA .....	xxviii
Table ES-5. Daily TMDL (counts/day) for E. coli bacteria in the tidal impairments within the project area. The TMDL includes future growth in the WLA .....	xxviii
Table ES- 6. Dates, location, organizations present, number of attendees, and purpose of public meetings throughout the TMDL development.....	xxx

Table 1-1. Summary of stream segments impaired for E. coli bacteria in the project area (based on the 2016, 2018, and 2020 305(b)/303(d) Water Quality Assessment Integrated Reports).....	9
Table 2-1. Acreage of TMDL watersheds in applicable counties .....	14
Table 2-2. Distribution of soils in the project area .....	16
Table 2-3. Hydrologic soil group descriptions .....	17
Table 2-4. Distribution of hydrologic soil groups in the project area.....	18
Table 2-5. Daily summary climatic station in the project area (NCDC, 2019) .....	20
Table 2-6. Land use distribution within the TMDL watersheds .....	23
Table 2-7. Land use descriptions .....	25
Table 2-8. USGS stream flow gages and associated characteristics used for this TMDL.....	26
Table 2-9. DEQ bacteria monitoring stations in project area with samples collected during 2000 through 2018 .....	28
Table 2-10. Summary of instream E. coli bacteria monitoring data for the DEQ stations used for project area impairment listings during the 2016 (2009 through 2014) or 2018 (2011 through 2016) assessment periods .....	29
Table 3-1. Applicable facilities with active VPDES individual permits that discharge in the project area .....	32
Table 3-2. Facilities with VPDES general permits that discharge in the project area but are not expected to discharge bacteria .....	32
Table 3-3. Biosolids application in the project area .....	35
Table 3-4. Population for each county in the project area .....	37

Table 3-5. Number of housing units in each county in the project area .....	37
Table 3-6. Estimated population and number of housing unit within the project area .....	37
Table 3-7. Number of houses that use public sewers, septic systems, or other means of sewage disposal (based on 1990 Census data) in the project area.....	38
Table 3-8. Estimated number of straight pipes, pit privies, and failing septic systems in the project area .....	38
Table 3-9. Estimated dog populations in project area.....	39
Table 3-10. Estimated livestock populations in the project area .....	40
Table 3-11. Average daily fecal coliform bacteria production rates for each livestock type .....	40
Table 3-12. Average daily schedule for beef cattle by month .....	41
Table 3-13. Average daily schedule for dairy cattle by month.....	41
Table 3-14. Wildlife habitats and population densities in the project area.....	42
Table 3-15. Estimated wildlife populations in the project area .....	43
Table 4-1. DEQ monitoring stations used in the calibration and validation of the HSPF model .	47
Table 4-2. TMDL Modeling Area Segments in Impaired Watersheds.....	49
Table 4-3. A reclassification scheme to convert 2011 NLCD land use classes to fewer classes for modeling .....	53
Table 4-4. The hydrologic model calibration summary at USGS Station 01674500 .....	56
Table 4-5. The hydrologic calibration results -- error statistics at USGS Station 01674500 .....	56
Table 4-6. The project area HSPF model hydrologic validation summary at USGS Station 01674500.....	58

Table 4-7. The project area HSPF model hydrologic validation result error statistics at USGS Station 01674500 .....	58
Table 4-8. Comparison of modeled and observed geometric mean and the rate of exceedances of statistical threshold value criterion .....	64
Table 5-1. Bacteria load allocation scenarios for Aylett Creek TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml).....	69
Table 5-2. Annual load existing conditions and allocations and percent reduction per land use category for Aylett Creek TMDL Watershed .....	69
Table 5-3. Aylett Creek TMDL (counts/year) for E. coli .....	70
Table 5-4. Aylett Creek TMDL (counts/day) for E. coli .....	70
Table 5-5. Bacteria load allocation scenarios for Courthouse Creek TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml) .....	74
Table 5-6. Annual load existing conditions and allocations and percent reduction per land use category for Courthouse Creek TMDL Watershed.....	74
Table 5-7. Courthouse Creek TMDL (counts/year) for E. coli.....	75
Table 5-8. Courthouse Creek TMDL (counts/day) for E. coli.....	75
Table 5-9. Bacteria load allocation scenarios for Dickeys Swamp TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml) .....	79
Table 5-10. Annual load existing conditions and allocations and percent reduction per land use category for Dickeys Swamp TMDL Watershed.....	79
Table 5-11. Dickeys Swamp TMDL (counts/year) for E. coli .....	80

Table 5-12. Dickey's Swamp TMDL (counts/day) for E. coli.....	81
Table 5-13. Bacteria load allocation scenarios for Dogwood Fork TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml) .....	84
Table 5-14. Annual load existing conditions and allocations and percent reduction per land use category for Dogwood Fork TMDL Watershed .....	84
Table 5-15. Dogwood Fork TMDL (counts/year) for E. coli .....	85
Table 5-16. Dogwood Fork TMDL (counts/day) for E. coli .....	85
Table 5-17. Bacteria load allocation scenarios for Dorrell Creek TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml) .....	89
Table 5-18. Annual load existing conditions and allocations and percent reduction per land use category for Dorrell Creek TMDL Watershed.....	89
Table 5-19. Dorrell Creek TMDL (counts/year) for E. coli .....	90
Table 5-20. Dorrell Creek TMDL (counts/day) for E. coli.....	90
Table 5-21. Bacteria load allocation scenarios for Garnetts Creek TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml) .....	94
Table 5-22. Annual load existing conditions and allocations and percent reduction per land use category for Garnetts Creek TMDL Watershed.....	94
Table 5-23. Garnetts Creek TMDL (counts/year) for E. coli .....	95
Table 5-24. Garnetts Creek TMDL (counts/day) for E. coli.....	95

Table 5-25. Bacteria load allocation scenarios for Gravel Run TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml).....	99
Table 5-26. Annual load existing conditions and allocations and percent reduction per land use category for Gravel Run TMDL Watershed .....	99
Table 5-27. Gravel Run TMDL (counts/year) for E. coli .....	100
Table 5-28. Gravel Run TMDL (counts/day) for E. coli .....	101
Table 5-29. Wasteload allocations for Herring Creek TMDL watershed.....	105
Table 5-30. Bacteria load allocation scenarios for Herring Creek TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml) .....	105
Table 5-31. Annual load existing conditions and allocations and percent reduction per land use category for Herring Creek TMDL Watershed.....	106
Table 5-32. Herring Creek TMDL (counts/year) for E. coli.....	107
Table 5-33. Herring Creek TMDL (counts/day) for E. coli.....	107
Table 5-34. Bacteria load allocation scenarios for Market Swamp TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml) .....	111
Table 5-35. Annual load existing conditions and allocations and percent reduction per land use category for Market Swamp TMDL Watershed .....	111
Table 5-36. Market Swamp TMDL (counts/year) for E. coli .....	112
Table 5-37. Market Swamp TMDL (counts/day) for E. coli .....	112

Table 5-38. Bacteria load allocation scenarios for Mattaponi River TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml) .....	117
Table 5-39. Annual load existing conditions and allocations and percent reduction per land use category for Mattaponi River TMDL Watershed .....	117
Table 5-40. Mattaponi River TMDL (counts/year) for E. coli .....	118
Table 5-41. Mattaponi River TMDL (counts/day) for E. coli .....	118
Table 5-42. Bacteria load allocation scenarios for XDN-Garnetts Creek, UT TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml).....	123
Table 5-43. Annual load existing conditions and allocations and percent reduction per land use category for XDN-Garnetts Creek, UT TMDL Watershed .....	123
Table 5-44. XDN-Garnetts Creek, UT TMDL (counts/year) for E. coli .....	124
Table 5-45. XDN-Garnetts Creek, UT TMDL (counts/day) for E. coli .....	124
Table 5-46. Bacteria load allocation scenarios for XJG-Dickeys Swamp, UT TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml).....	129
Table 5-47. Annual load existing conditions and allocations and percent reduction per land use category for XJG-Dickeys Swamp, UT TMDL Watershed.....	129
Table 5-48. XJG-Dickeys Swamp, UT TMDL (counts/year) for E. coli .....	130
Table 5-49. XJG-Dickeys Swamp, UT TMDL (counts/day) for E. coli.....	130
Table 5-50. Estimated Annual Loads and Load Reductions of E. coli: Combined WLA and LA .....	135

Table 6-1. Existing condition annual loads per land use category for the tidal Mattaponi River (VAP-F23E_MPN03A06) TMDL Watershed.....	138
Table 6-2. Existing condition annual loads per land use category for the tidal Mattaponi River (VAP-F24E_MPN03A98) TMDL Watershed.....	139
Table 6-3. Daily E. coli TMDL for the Mattaponi River Tidal Segment (Counts/Day) .....	148
Table 6-4. Annual E. coli TMDL for the Mattaponi River Tidal Segment (Counts /Year) .....	148
Table 8-1. Public participation during TMDL development for the study area .....	158

## List of Figures

Figure ES-1. Map of TMDL watersheds, impairments, and assessment stations in the project area .....	xxiv
Figure 1-1. Map of Stream Segments impaired for E. coli bacteria in the project area (based on the 2016 and 2018 305(b)/303(d) Water Quality Assessment Integrated Reports).....	11
Figure 2-1. Impaired waterbodies and delineated subwatersheds within TMDL watersheds used in the assessment of watershed characteristics and pollutant sources .....	13
Figure 2-2. Hydrologic soil groups within the project area .....	19
Figure 2-3. NCDC climatic station in the project area .....	21
Figure 2-4. Land use distribution within the project area .....	24
Figure 2-5. Flow duration curves for three USGS gaging stations using data from 1990 through 2018.....	27

Figure 2-6. DEQ water quality monitoring stations and segments assessed as impaired for the recreational use due to exceedances of E. coli bacteria in the 2016 and 2018 Integrated Reports (VADEQ, 2018 and 2019) .....	30
Figure 3-1. General and Individual VPDES permits in the project area .....	33
Figure 4-1. TMDL Modeling Area Segments.....	52
Figure 4-2. The project area HSPF model hydrologic calibration results at USGS Station 01674500 .....	57
Figure 4-3. The project area HSPF model hydrologic validation results at USGS Station 01674500 .....	59
Figure 5-1. Aylett Creek 90-day geometric mean E. coli concentrations under existing and TMDL conditions.....	71
Figure 5-2. Aylett Creek daily average E. coli concentrations under existing and TMDL conditions .....	72
Figure 5-3. Aylett Creek exceedance frequency of the STV based on the rolling 90-day average E. coli concentrations under existing and TMDL conditions.....	73
Figure 5-4. Courthouse Creek the rolling 90-Day geometric mean E. coli concentrations under existing and TMDL conditions .....	76
Figure 5-5. Courthouse Creek daily average E. coli concentrations under existing and TMDL conditions.....	77
Figure 5-6. Courthouse Creek exceedance frequency of the STV based on the rolling 90-day average E. coli concentrations under existing and TMDL conditions.....	78
Figure 5-7. Dickeys Swamp the rolling 90-day geometric mean E. coli concentrations under existing and TMDL conditions .....	81

Figure 5-8. Dickey's Swamp daily average E. coli concentrations under existing and TMDL conditions .....	82
Figure 5-9. Dickey's Swamp exceedance frequency of the STV based on the rolling 90-day average E. coli concentrations under existing and TMDL conditions .....	83
Figure 5-10. Dogwood Fork the rolling 90-day geometric mean E. coli concentrations under existing and TMDL conditions .....	86
Figure 5-11. Dogwood Fork daily average E. coli concentrations under existing and TMDL conditions .....	87
Figure 5-12. Dogwood Fork exceedance frequency of the STV based on the rolling 90-day average E. coli concentrations under existing and TMDL conditions .....	88
Figure 5-13. Dorrell Creek the rolling 90-day geometric mean E. coli concentrations under existing and TMDL conditions .....	91
Figure 5-14. Dorrell Creek daily average E. coli concentrations under existing and TMDL conditions .....	92
Figure 5-15. Dorrell Creek exceedance frequency of the STV based on the rolling 90-day average E. coli concentrations under existing and TMDL conditions .....	93
Figure 5-16. Garnetts Creek the rolling 90-day geometric mean E. coli concentrations under existing and TMDL conditions .....	96
Figure 5-17. Garnetts Creek daily average E. coli concentrations under existing and TMDL conditions .....	97
Figure 5-18. Garnetts Creek exceedance frequency of the STV based on the rolling 90-day average E. coli concentrations under existing and TMDL conditions .....	98
Figure 5-19. Gravel Run the rolling 90-day geometric mean E. coli concentrations under existing and TMDL conditions .....	102

Figure 5-20. Gravel Run daily average E. coli concentrations under existing and TMDL conditions .....	103
Figure 5-21. Gravel Run exceedance frequency of the STV based on the rolling 90-day average E. coli concentrations under existing and TMDL conditions.....	104
Figure 5-22. Herring Creek the rolling 90-day geometric mean E. coli concentrations under existing and TMDL conditions .....	108
Figure 5-23. Herring Creek daily average E. coli concentrations under existing and TMDL conditions.....	109
Figure 5-24. Herring Creek exceedance frequency of the STV based on the rolling 90-day average E. coli concentrations under existing and TMDL conditions .....	110
Figure 5-25. Market Swamp the rolling 90-day geometric mean E. coli concentrations under existing and TMDL conditions .....	114
Figure 5-26. Market Swamp daily average E. coli concentrations under existing and TMDL conditions.....	115
Figure 5-27. Market Swamp exceedance frequency of the STV based on the rolling 90-day average E. coli concentrations under existing and TMDL conditions .....	116
Figure 5-28. Mattaponi River the rolling 90-day geometric mean E. coli concentrations under existing and TMDL conditions .....	120
Figure 5-29. Mattaponi River daily average E. coli concentrations under existing and TMDL conditions.....	121
Figure 5-30. Mattaponi River exceedance frequency of the STV based on the rolling 90-day average E. coli concentrations under existing and TMDL conditions.....	122
Figure 5-31. XDN-Garnetts Creek, UT the rolling 90-day geometric mean E. coli concentrations under existing and TMDL conditions .....	126

Figure 5-32. XDN-Garnetts Creek, UT daily average E. coli concentrations under existing and TMDL conditions.....	127
Figure 5-33. XDN-Garnetts Creek, UT exceedance frequency of the STV based on the rolling 90-day average E. coli concentrations under existing and TMDL conditions .....	128
Figure 5-34. XJG-Dickeys Swamp, UT the rolling 90-day geometric mean E. coli concentrations under existing and TMDL conditions .....	132
Figure 5-35. XJG-Dickeys Swamp, UT daily average E. coli concentrations under existing and TMDL conditions.....	133
Figure 5-36. XJG-Dickeys Swamp, UT exceedance frequency of the STV based on the rolling 90-day average E. coli concentrations under existing and TMDL conditions .....	134
Figure 6-1. Modeling process for the bacteria TMDL.....	138
Figure 6-2. York River model domain with the modelling grids, project area outlined in red ..	140
Figure 6-3. Map of TMDL subwatersheds and water quality stations .....	141
Figure 6-4. Mattaponi River salinity observation stations.....	142
Figure 6-5. Modeled (lines) and observed (circles) salinities at station RET4.2 (upper panel) and modeled salinity at TF4.4 (no observed data during this period) (lower panel) in the Mattaponi River (red lines are at the river bottom and blue lines are at the surface). .....	143
Figure 6-6. Modeled (solid blue lines) and observed (circles) bacteria concentrations, and rolling 90-day GM (solid red lines) and rolling 90-day STV (solid green lines) at two DEQ monitoring stations. The dashed red lines are GM (126 counts/100 ml) and STV (410 counts/100 ml).....	144
Figure 6-7. Modeled (solid blue lines) and observed (circles) bacteria concentrations, and rolling 90-day GM (solid red lines) at two DEQ monitoring stations. The dashed red lines are GM (126 counts/100 ml) and STV (410 counts/100 ml).....	145

## List of Acronyms

**AVMA:** American Veterinary Medical Association  
**ACQOP:** Accumulation Rate of Constituent  
**AFO:** Animal Feeding Operation  
**BMP:** Best Management Practice  
**Cfs:** cubic feet per second  
**Cfu/Count:** colony forming units  
**CWA:** Clean Water Act  
**DCR:** Virginia Department of Conservation and Recreation  
**DEM:** Digital Elevation Model  
**DEQ:** Virginia Department of Environmental Quality  
**DMR:** Discharge Monitoring Report  
**DOC:** Department of Corrections  
**EFDC:** Environmental Fluid Dynamics Computer Code  
**EPA:** Environmental Protection Agency  
**FG:** Future Growth  
**GHCND:** Global Historical Climatology Network Daily  
**GIS:** Geographic Information System  
**GM:** Geometric Mean  
**HSPEXP:** Expert System for Calibration of the Hydrological Simulation Program - FORTRAN  
**HSPF:** Hydrologic Simulation Program-Fortran  
**HUC:** Hydrologic Unit Code  
**HSUS:** Humane Society of the United States  
**IP:** Implementation Plan  
**JAXA:** Japan Aerospace Exploration Agency  
**LA:** Load Allocation  
**LSPC:** Loading Simulation Program in C++  
**MGD:** Million gallons per day  
**ml:** Milliliter  
**MS4:** Municipal separate storm sewer system  
**MOU:** Memorandum of Understanding  
**NASA:** National Aeronautics and Space Administration  
**NASS:** National Agricultural Statistics Service  
**NCDC:** National Climatic Data Center  
**NHD:** National Hydrography Dataset  
**NGVD29:** National Geodetic Vertical Datum of 1929  
**NLCD:** National Land Coverage Database  
**NOAA:** National Oceanic and Atmospheric Association  
**NPDES:** National Pollution Discharge Elimination System  
**NRCS:** Natural Resources Conservation Service  
**NWBD:** National Watershed Boundary Dataset  
**MOS:** Margin of Safety  
**QA/QC:** Quality Assurance and Quality Control  
**SSURGO:** Soil Survey Geographic Database  
**SQOLIM:** Storage Limits of Constituents

**STV:** Statistical Threshold Value  
**SWCB:** State Water Control Board  
**SWCD:** Soil and Water Conservation District  
**TAC:** Technical Advisory Committee  
**TMDL:** Total Maximum Daily Load  
**TRMM:** Tropical Rainfall Measurement Mission  
**USGS:** U.S. Geological Survey  
**VADOC:** Virginia Department of Corrections  
**VCE:** Virginia Cooperative Extension  
**VDH:** Virginia Department of Health  
**VPA:** Virginia Pollution Abatement  
**VPDES:** Virginia Pollutant Discharge Elimination System  
**VSMP:** Virginia Stormwater Management Program  
**UAA:** Use Attainability Analysis  
**USDA:** United States Department of Agriculture  
**UT:** Unnamed Tributary  
**VCAP:** Virginia Conservation Assistance Program  
**VDOT:** Virginia Department of Transportation  
**VDGIF:** Virginia Department of Game and Inland Fisheries  
**VDWR:** Virginia Department of Wildlife Resources (formally VDGIF)  
**VECOS:** Virginia Estuarine and Coastal Observing System  
**VIMS:** Virginia Institute of Marine Science  
**WDM:** Watershed Data Management  
**WLA:** Wasteload Allocation  
**WQIF:** Water Quality Improvement Fund  
**WQMIRA:** Water Quality Monitoring, Information, and Restoration Act  
**WQMP:** Water Quality Management Plan  
**WQS:** Water Quality Standard  
**WWTP:** Wastewater Treatment Plant

Page Left Intentionally Blank

DRAFT

## EXECUTIVE SUMMARY

---

This report presents the development of bacteria Total Maximum Daily Loads (TMDLs) for 12 impaired streams composed of 16 impaired 305(b)/303(d) stream segments (assessment units) within the lower Mattaponi River project area. Virginia's 2016 and 2018 Section 303(d) list of Impaired Waters includes Aylett Creek, Courthouse Creek, Dickey's Swamp, Dogwood Fork, Dorrell Creek, Garnetts Creek, Gravel Run, Herring Creek, Market Swamp, sections of the Mattaponi River (including non-tidal and tidal segments), and unnamed tributaries (UT) to Dickey's Swamp and Garnetts Creek (VADEQ, 2018a; VADEQ, 2019). Two more segments were listed as impaired due to *E. coli* bacteria in Virginia's 2020 305(b)/303(d) IR (VADEQ, 2020). These segments of Dickey's Swamp and the tidal Mattaponi River are not included in this report for TMDLs; however, they will be addressed through the nesting process in the 2022 Water Quality Assessment Integrated Report. The Virginia Department of Environmental Quality (DEQ) has described the impaired segments as presented in Table ES-1. These segments are impaired because more than 10% of the total samples in the assessment period exceeded the primary contact recreation use bacteria criteria.

### Applicable Water Quality Standards

Section 303(d) of the Clean Water Act (CWA) and the United States Environmental Protection Agency's Water Quality Planning and Management Regulations require states to develop total maximum daily loads (TMDLs) for waterbodies that exceed water quality standards (WQS). A TMDL represents the total pollutant loading that a waterbody can receive without exceeding the WQS. The goal of a TMDL is to restore impaired waters to attain water quality standards. Water quality standards consist of statements that describe water quality requirements and include three components: 1) designated uses, 2) water quality criteria to protect designated uses, and 3) an anti-degradation policy. Through the 2020 assessment period (calendar years 2013 through 2018), the DEQ used the following bacteria criteria to assess for primary contact recreation uses in surface waters:

In freshwaters (including tidal fresh), *Escherichia coli* (*E. coli*) bacteria is estimated in colony-forming units (counts) and shall not exceed a geometric mean of 126 counts/100 ml calculated

with a minimum of four weekly samples over a calendar month; if there are insufficient samples to calculate the calendar monthly geometric mean, no more than 10% of the total samples in an assessment period can exceed 235 counts/100 ml. The 235 counts/100 ml criterion is referred to in this report as the assessment criterion.

In 2019, DEQ adopted new criteria, and used these updated criteria to develop this TMDL:

In freshwater, *E. coli* bacteria shall not exceed a geometric mean of 126 counts/100 ml and shall not have greater than a 10% excursion frequency of the Statistical Threshold Value (STV) of 410 counts/100 ml, both in an assessment period of up to 90 days.

*Table ES-1. Summary of Stream Segments impaired for E. coli in the project area (based on the 2016, 2018, and 2020 305(b)/303(d) Water Quality Assessment Integrated Report)*

TMDL Watershed/Impaired Stream Name	Cause Group Code	305(b)/303(d) Assessment Unit ID	Year First Listed as Impaired	Impairment Size	County	Monitoring Station	Sample Exceedance of <i>E. coli</i> Assessment Criterion (235 counts/100 ml)
Aylett Creek	F23R-04-BAC	VAP-F23R_AYL01A12	2012	6.83 miles	King William	8-AYL002.27	3 of 11 (27.3%)
Courthouse Creek	F24R-03-BAC	VAP-F24R_CTH01A00	2016	0.72 miles	King and Queen	8-CTH001.96	3 of 12 (25.0%)
Dickeys Swamp	F23R-08-BAC	VAP-F23R_DKW01B00	2014	4.33 miles	King and Queen	8-DKW004.31	4 of 12 (33.3%)
Dickeys Swamp	F23R-13-BAC	VAP-F23R_DKW01A00	2020	3.99 miles	King and Queen	8-DKW005.73	3 of 12 (25.0%)
Dogwood Fork	F23R-11-BAC	VAP-F23R_DWD01A00	2014	2.91 miles	King and Queen	8-DWD000.77	4 of 12 (33.3%)
Dorrell Creek	F21R-08-BAC	VAN-F21R_DRL01A18	2018	4.96 miles	King William	8-DRL000.85	2 of 12 (16.7%)
Garnetts Creek	F23R-01-BAC	VAP-F23R_GNT01A00	2010	2.83 miles	King and Queen	8-GNT001.54	6 of 23 (26.1%)
Gravel Run	F21R-09-BAC	VAN-F21R_GVL01A18	2018	3.54 miles	King and Queen	8-GVL000.56	5 of 12 (41.7%)
Herring Creek	F21R-05-BAC	VAN-F21R_HER01B02	2016	5.09 miles	King William	8-HER005.12	2 of 12 (16.7%)
Herring Creek	F21R-05-BAC	VAN-F21R_HER01A06	2018	2.14 miles	King William	8-HER000.33	4 of 24 (16.7%)
Market Swamp	F23R-09-BAC	VAP-F23R_MKT01B00	2014	2.01 miles	King and Queen	8-MKT001.04	2 of 12 (16.7%)
Mattaponi River (non-tidal)	F21R-06-BAC	VAN-F21R_MPN01C02 VAN-F21R_MPN01B02	2016	8.00 miles	King and Queen/King William	8-MPN054.17	5 of 36 (13.9%)
Mattaponi River (tidal)	F23E-02-BAC	VAP-F23E_MPN03A06	2016	1.76 square miles	King and Queen/King William	8-MPN034.33	2 of 9 (22.2%)
Mattaponi River (tidal)	F24E-02-BAC	VAP-F24E_MPN03A98	2018	1.38 square miles	King and Queen/King William	8-MPN017.46	4 of 35 (11.4%)
Mattaponi River (tidal)	F24E-03-BAC	VAP-F23E_MPN02A98	2020	0.16 square miles	King and Queen/ King William	8-MPN039.10	5 of 33 (15.2%)
XDN-Garnetts Creek, UT	F23R-10-BAC	VAP-F23R_XJG01A14	2014	1.99 miles	King and Queen	8-XJG000.08	5 of 12 (41.7%)
XJG-Dickeys Swamp, UT	F23R-12-BAC	VAP-F23R_XDN01A00	2016	2.53 miles	King and Queen	8-XDN000.12	2 of 11 (18.2%)

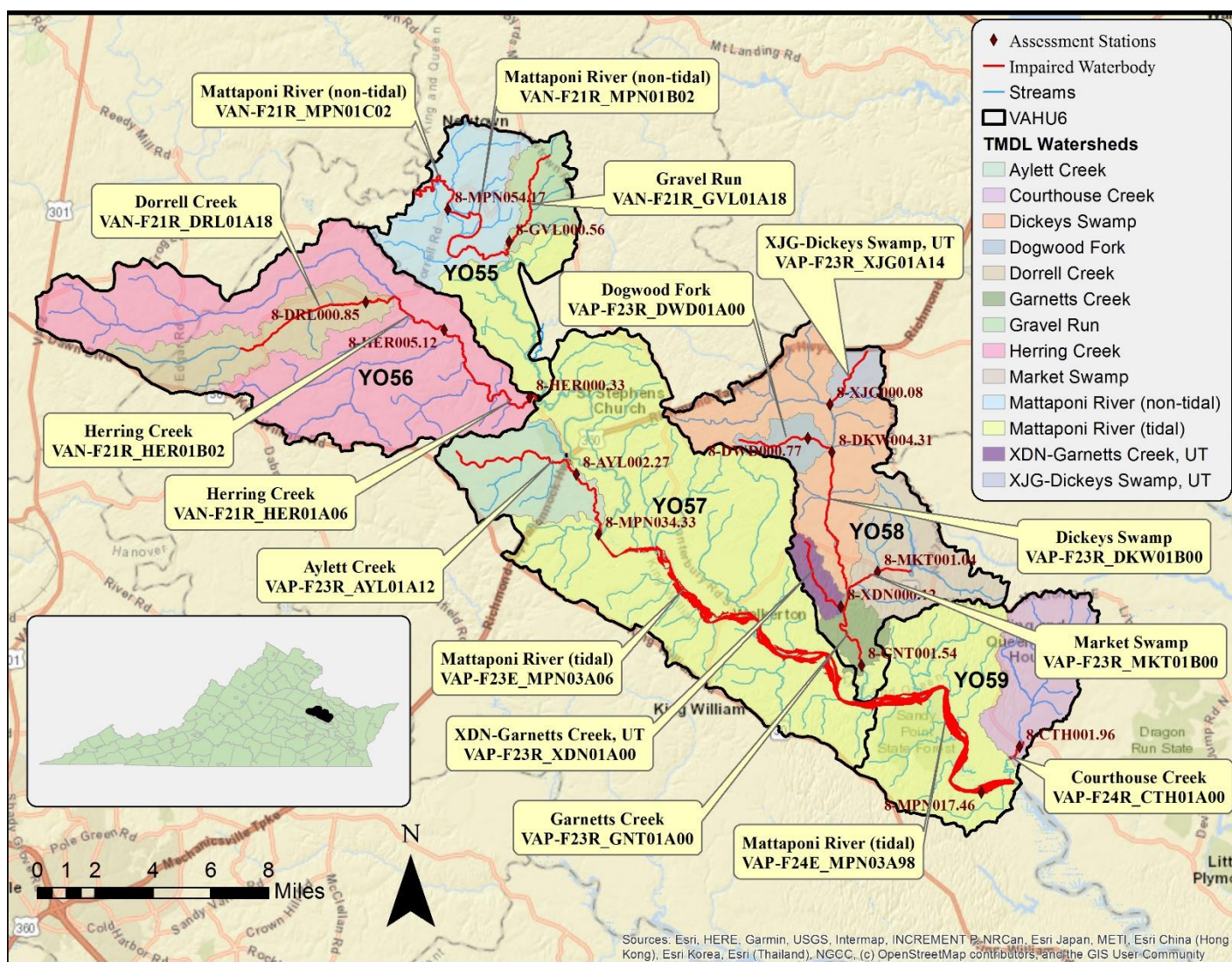


Figure ES-1. Map of TMDL watersheds, impairments, and assessment stations in the project area

## Description of Project Area

The lower Mattaponi River project area is part of the Mattaponi River subbasin (USGS HUC 02080105). The project area is located in Caroline, Essex, King and Queen, and King William Counties within the Rolling Coastal Plain of Southeastern Plains Ecoregion. The land use within the project area is predominantly forest and cropland. The Mattaponi River generally flows southeast and discharges into the York River, which flows into the Chesapeake Bay.

## Pollutant Sources

The sources of bacteria that may contaminate surface water include wastewater discharges, direct deposition from animal and human sources, and contaminated runoff. There are currently seven permitted sources that discharge into the lower Mattaponi River project area. One facility has an active individual permit that is expected to discharge the applicable pollutant of concern (bacteria) within the project area. This facility is characterized as minor municipal (discharge design flow less than 1.0 million gallons per day). The other six facilities were not considered as bacteria point sources. Some bacteria loads also originate from non-point sources such as livestock, wildlife, pets, and humans.

## TMDL Technical Approach

Non-tidal segments were modeled using Hydrological Simulation Program FORTTRAN (HSPF) (Bicknell et al., 2005; Duda et al., 2001), a model that excels in simulating systems with unidirectional flow. HSPF simulated the hydrology and the fate and transport of fecal coliform bacteria. HSPF is a continuous model that can represent fate and transport of pollutants on both the land surface and in the stream. Available United States Geological Survey (USGS) flow gage data, weather data, and water quality data were reviewed to select suitable modeling periods for hydrologic and water quality calibration and validation of the model. Water quality modeling was conducted with fecal coliform inputs, and then a translator equation was used to convert the output to *E. coli* for the final TMDLs.

The 3-dimensional Environmental Fluid Dynamics Computer Code (EFDC) (Hamrick, 1992; Park et al., 1995) was used to simulate the bacteria transport in the Mattaponi River tidal, estuarine segments. The EFDC model uses a computational grid to represent the study area. The

grid is comprised of cells connected through the modeling process. The grid resolution (cell size) determines the level of spatial resolution in the model and the model efficiency.

### TMDL Endpoints

The TMDL endpoint is an expression of the desired level of pollutant that will not exceed water quality standards and is used to evaluate the attainment of acceptable water quality. The numeric criteria in the bacteria water quality standard is a measurable endpoint which represents the overall goal of the TMDL.

The endpoints for these TMDLs are intended to protect the primary contact recreation designated use. TMDL allocation scenarios were developed using two endpoints:

1. No exceedances of the geometric mean criterion for any 90 day period AND
2. No 90-day period with an exceedance frequency greater than 10% of the statistical threshold value.

### TMDL Description and Calculations

A Total Maximum Daily Load (TMDL) is an equation that describes how much of a pollutant a waterbody can receive without exceeding the WQS. There are four components to a TMDL equation - Waste Load Allocation (WLA), Load Allocation (LA), Margin of Safety (MOS) and Future Growth (FG). The WLA is the portion of the allowable loading allocated to permitted point sources. The LA is the allocation assigned to nonpoint sources like livestock, wildlife, septic tanks, and pets. Land use data and local knowledge from stakeholders contributed to the LA calculation. TMDL equations also contain either an explicit or implicit MOS to account for uncertainties associated with source assessment, model parameterization, etc. An implicit MOS was used in these bacteria TMDLs in all non-tidal watersheds by using conservative estimations of all factors that would affect bacteria loadings in the watershed (e.g., animal numbers, bacteria densities, parameters that are used to characterize manure contributions to the stream). TMDLs were calculated for the Mattaponi River tidal impairments using an explicit 5% MOS. Future growth involves planning for future conditions that may require expanding existing Wastewater Treatment Plants (WWTPs), building new WWTPs, issuance of other new permits, or accounting for anticipated land conversions in a TMDL watershed. It is DEQ's practice that the future growth WLA should be 2% of the TMDL if a TMDL watershed has no existing permitted

xxvi

dischargers or if the existing WLA in the watershed represents 10% or less of the TMDL. If the existing WLA in the watershed is greater than 10% of the TMDL, the future growth WLA is 1% of the TMDL. The future growth WLA for all impairments in this report were calculated as 2% of the TMDL. Annual (Table ES-2) and daily (Table ES-3) TMDLs were calculated for each non-tidal TMDL watershed. Annual (Table ES-4) and daily (Table ES-5) TMDLs were also calculated for the Mattaponi River tidal impairments. Additionally, seasonal variations and critical conditions for stream flow, loading, and water quality parameters were all taken into account in the development of these TMDLs.

*Table ES-2. Annual TMDL (counts/year) for E. coli bacteria in the non-tidal impairments within the project area. The TMDLs include future growth in the WLAs*

Impairment	Existing Load (counts/year)	Reductions (%)	WLA (counts/year)	LA (counts/year)	MOS	TMDL (counts/yr)
Aylett Creek	1.24E+13	2.5	2.42E+11	1.18E+13	Implicit	1.21E+13
<i>Future Growth</i>			2.42E+11			
Courthouse Creek	7.26E+12	2.8	1.41E+11	6.91E+12	Implicit	7.05E+12
<i>Future Growth</i>			1.41E+11			
Dickeys Swamp	1.16E+13	4.6	2.22E+11	1.09E+13	Implicit	1.11E+13
<i>Future Growth</i>			2.22E+11			
Dogwood Fork	1.12E+12	19.8	1.79E+10	8.79E+11	Implicit	8.97E+11
<i>Future Growth</i>			1.79E+10			
Dorrell Creek	3.21E+12	10.5	5.75E+10	2.82E+12	Implicit	2.88E+12
<i>Future Growth</i>			5.75E+10			
Garnetts Creek	4.56E+12	4.4	8.72E+10	4.27E+12	Implicit	4.36E+12
<i>Future Growth</i>			8.72E+10			
Gravel Run	6.71E+12	18	1.10E+11	5.39E+12	Implicit	5.50E+12
<i>Future Growth</i>			1.10E+11			
Herring Creek	3.01E+13	5.7	6.30E+11	2.77E+13	Implicit	2.83E+13
VA0023329			6.44E+10			
<i>Future Growth</i>			5.66E+11			
Market Swamp	6.15E+12	10.6	1.10E+11	5.38E+12	Implicit	5.49E+12
<i>Future Growth</i>			1.10E+11			
Mattaponi River (non-tidal)	7.45E+13	32.8	1.00E+12	4.91E+13	Implicit	5.01E+13
<i>Future Growth</i>			1.00E+12			
XDN-Garnetts Creek, UT	1.79E+12	26.1	2.65E+10	1.30E+12	Implicit	1.33E+12
<i>Future Growth</i>			2.65E+10			
XJG-Dickeys Swamp, UT	1.18E+12	14.7	2.01E+10	9.86E+11	Implicit	1.01E+12
<i>Future Growth</i>			2.01E+10			

*Table ES- 3. Daily TMDL (counts/day) for E. coli bacteria in the non-tidal impairments within the project area. The TMDLs include future growth in the WLAs*

Impairment	WLA	LA	MOS	TMDL (counts/day)
Aylett Creek	6.62E+08	1.25E+11	Implicit	1.26E+11
Courthouse Creek	3.86E+08	7.25E+10	Implicit	7.29E+10
Dickeys Swamp	6.07E+08	1.15E+11	Implicit	1.15E+11
Dogwood Fork	4.91E+07	9.27E+09	Implicit	9.32E+09
Dorrell Creek	1.58E+08	2.95E+10	Implicit	2.97E+10
Garnetts Creek	2.39E+08	4.46E+10	Implicit	4.48E+10
Gravel Run	3.01E+08	5.59E+10	Implicit	5.62E+10
Herring Creek	2.26E+09	2.87E+11	Implicit	2.89E+11
Market Swamp	3.01E+08	5.64E+10	Implicit	5.67E+10
Mattaponi River (non-tidal)	2.74E+09	5.19E+11	Implicit	5.22E+11
XDN-Garnetts Creek, UT	7.26E+07	1.36E+10	Implicit	1.36E+10
XJG-Dickeys Swamp, UT	5.51E+07	1.04E+10	Implicit	1.05E+10

*Table ES-4. Annual TMDL (counts/year) for E. coli bacteria in the tidal impairments within the project area. The TMDL includes future growth in the WLA*

Impairment	WLA (counts/year)	LA (counts/year)	MOS	TMDL (counts/yr)
Mattaponi River (tidal)	1.87E+11	8.68E+12	4.67E+11	9.33E+12
<i>Future Growth</i>	<i>1.87E+11</i>			

*Table ES-5. Daily TMDL (counts/day) for E. coli bacteria in the tidal impairments within the project area. The TMDL includes future growth in the WLA*

Impairment	WLA (counts/day)	LA (counts/day)	MOS	TMDL (counts/yr)
Mattaponi River (tidal)	1.14E+9	5.32E+10	2.86E+9	5.72E+10
<i>Future Growth</i>	<i>1.14E+9</i>			

#### TMDL Implementation/Reasonable Assurance

The goal of the TMDL program is to establish a three-step path that will lead to the attainment of water quality standards. This report represents the culmination of the first step in this process, which is the development of TMDL equations to guide the attainment of water quality.

Once developed, DEQ intends to incorporate the TMDL report into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e). In response to a Memorandum of Understanding (MOU) between the United States Environmental Protection Agency (EPA) and DEQ, DEQ also submitted a draft Continuing Planning Process to EPA in which DEQ commits to regularly updating the WQMPs (40 CFR. 130.5). Thus, the WQMPs will be, among other things, the repository for all TMDLs developed within a river basin.

The final step is to develop a TMDL Implementation Plan, initiate its recommendations, and to monitor stream water quality to determine if water quality standards are being attained. Stakeholders will work together to create a plan outlining appropriate Best Management Practices (BMPs) for the project area. The purpose, location, parameters, frequency, and duration of the monitoring will be determined by DEQ staff, the Implementation Plan Steering Committee, and local stakeholders. Whenever possible, the location of the follow-up monitoring station(s) will be the same as the listing station(s). At a minimum, the monitoring stations must be representative of the original impaired segments. The details of the follow-up monitoring will be outlined in the Annual Water Monitoring Plan prepared by each DEQ Regional Office. Other agency personnel, stakeholders, etc. may provide input on the Annual Water Monitoring Plan.

#### Public Participation

The project team elicited public participation at every stage of the TMDL development in order to receive input from stakeholders and to apprise the stakeholders of the progress made (Table ES-6). The 30-day public comment period ended on **January 11, 2021** DEQ received [#] comments on the draft report.

*Table ES- 6. Dates, location, organizations present, number of attendees, and purpose of public meetings throughout the TMDL development*

<b>Date (Meeting)</b>	<b>Location</b>	<b>Organizations in Attendance</b>	<b>Numbers of Attendees</b>	<b>Purpose</b>
1 <sup>st</sup> TAC Meeting (10/03/2018)	King and Queen Branch Library, St. Stephens Church, VA	DEQ, VIMS, Streams Tech, Three Rivers SWCD, King William County, Caroline County	11	Introduce the TMDL process, present local stream impairments, and solicit comments from the stakeholders. Discuss potential local sources of bacteria.
1 <sup>st</sup> Public Meeting (10/15/2018)	King and Queen Branch Library, St. Stephens Church, VA	DEQ, Virginia Tech BSE, Local Soil and Water Conservation Districts (SWCD), Northern Neck PDC, VDH, Natural Resource Conservation Service	11	Introduce the TMDL to stakeholders. Receive feedback about outreach strategies. Identify areas for collaboration. Initiate discussions about local land use.
2 <sup>nd</sup> TAC Meeting (05/08/2019)	King and Queen Branch Library, St. Stephens Church, VA	DEQ, VIMS, Streams Tech, King William County, King and Queen County, VADOC, VDH, King and Queen Fish Hatchery, Caroline County	17	Review the project and TMDL process with stakeholders and discuss the source assessment.
3 <sup>rd</sup> TAC Meeting (06/26/2019)	King and Queen Branch Library, St. Stephens Church, VA	DEQ, VIMS, Streams Tech, VADOC, VDGIF (VDWR), local residents	11	Review the project and TMDL process with stakeholders and discuss the draft loadings and allocations.
Final Public Meeting (12/09/2020)	Virtual Meeting			

# 1 INTRODUCTION

---

## 1.1 Regulatory and Guidance Basis

The Clean Water Act (CWA) passed as U.S. law in 1972, and requires that all streams, rivers, and lakes meet water quality standards to promote safe habitat and water use. States must regularly monitor and report on the health of local waterbodies. If a waterbody does not meet the safe use standards, the waterbody is listed as “impaired”, or not meeting its use. Impaired waterbodies require pollution cleanup policies from the states.

As required by the CWA and Virginia’s 1997 Water Quality Monitoring, Information, and Restoration Act (WQMIRA), the Virginia Department of Environmental Quality (DEQ) is responsible for compiling a list of all assessed waters (305(b) report) and a list of the impaired waters (303(d) list) in the state, including the details of the cause(s) of each impairment and the potential source(s) of each pollutant. The 305(b) report and 303(d) list are compiled every two years in a statewide 305(b)/303(d) Water Quality Assessment Integrated Report; the most recent approved report is the 2020 Integrated Report, which is based on water quality data collected during 2013 through 2018.

Section 303(d) of the CWA and the Environmental Protection Agency's (EPA's) Water Quality Planning and Management Regulations (40 CFR Part 130) require Total Maximum Daily Loads (TMDLs) for waterbodies that are not meeting water quality standards (WQS). WQMIRA also requires DEQ to develop and implement TMDLs for impaired waters. A TMDL is the total daily amount of a pollutant that can enter a waterbody without exceeding water quality standards. The allowable loading amounts are based on the relationship between pollutants and in-stream water quality conditions. By following the TMDL process, states can establish water quality-based controls to reduce pollution from both point and nonpoint sources to restore and maintain the quality of their water resources (USEPA, 2001). Water quality-based controls are guided by water quality standards, such as a discharge limit for a permit. TMDLs are distributed for public comment and then submitted to the Virginia State Water Control Board (SWCB), followed by the EPA for approval.

DEQ is the lead agency for coordinating TMDLs statewide. DEQ focuses its efforts on all aspects of the reduction and prevention of pollution to state waters. To stimulate a more effective TMDL process, DEQ collaborates with other Virginia agencies and stakeholder groups, including, but not limited to:

- The Department of Conservation and Recreation (DCR)
- The Virginia Department of Health (VDH)
- Regional Planning Commissions
- Soil and Water Conservation Districts (SWCDs)
- Local jurisdictions

DEQ ensures compliance and coordinates public participation based on guidelines from the CWA, the Water Quality Planning Regulations, and WQMIRA.

## 1.2 Applicable Water Quality Standards

EPA has recommended that all states adopt an *Escherichia Coli* (*E. coli*) or *enterococci* standard for freshwater and *enterococci* criteria for transition and saltwater because there is a strong correlation between the concentration of these organisms and the incidence of gastrointestinal illness. *E. coli* and *enterococci* are bacteria that can be found in the intestinal tract of warm-blooded animals and are subsets of the fecal coliform and fecal streptococcus groups, respectively. In line with this recommendation, Virginia adopted and published revised bacteria criteria using the *E. coli* concentration in freshwater (including tidal freshwater) and *enterococci* in transition and saltwater instead of the fecal coliform concentration on June 17, 2002. The revised criteria became effective on January 15, 2003 and were updated again in 2019. The impairments were based on the 2003 revised criteria, but the updated 2019 criteria were used for the TMDL. The *E. coli* criteria applies to all impairments in this project because they are all freshwater (including tidal freshwater). As of 2019, the *E. coli* standards of 9VAC25-260-170 described below apply (SWCB, 2019):

“In freshwater, *E. coli* bacteria shall not exceed a geometric mean of 126 counts/100 ml and shall not have greater than a 10% excursion frequency of the Statistical Threshold Value (STV) of 410 counts/100 ml, both in an assessment period of up to 90 days.”

In freshwater, *E. coli* is the primary applicable water quality target. However, the loading rates for watershed-based modeling are available only in terms of fecal coliform. Therefore, the following translator equation is applied to convert instream fecal coliform concentrations to instream *E. coli* bacteria concentrations (VADEQ, 2003) and estimate *E. coli* loads based on the model results.

$$\log_2 EC = -0.0172 + 0.91905 * \log_2 FC$$

where: EC = *E. coli* bacteria concentration in counts/100 ml

FC = fecal coliform bacteria concentration in counts/100 ml

The modeled daily fecal coliform concentrations are converted to daily *E. coli* concentrations using the translator equation. Because the TMDL development process must also account for seasonal and annual variations in precipitation, flow, land use, and pollutant contributions, the conversion of daily concentrations ensures that TMDLs, when implemented, will not result in exceedances under a wide variety of scenarios affecting bacteria loading.

### 1.2.1 Designated Uses

Virginia Water Quality Standards (9VAC25-260-10) states that:

“All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish.”

### 1.3 TMDL Endpoints

A TMDL is established to reduce a pollutant to a level that will not exceed water quality standards. The TMDL endpoint is an expression of that desired level and is used to evaluate the attainment of acceptable water quality. The numeric criteria in the bacteria water quality standard is a measurable endpoint which represents the overall goal of the TMDL.

TMDL endpoints are intended to protect the primary contact recreation designated use. TMDL allocation scenarios for this project were developed using two endpoints:

1. No exceedances of the geometric mean criterion in any 90-day period AND

2. No 90-day period with an exceedance frequency greater than 10% of the statistical threshold value.

### 1.3.1 Study Area Description & List of impairments

This project includes 12 impaired streams composed of 16 impaired 305(b)/303(d) stream segments (assessment units) (Table 1-1). The Mattaponi River includes both tidal and non-tidal segments. The original scope of this project included 12 segments from streams included in Virginia's 2016 305(b)/303(d) Water Quality Assessment Integrated Report (IR) as impaired due to *E. coli* bacteria concentrations that do not meet the state's water quality criteria for the recreational designated use (VADEQ, 2018a). Four more segments were included in Virginia's 2018 305(b)/303(d) IR (VADEQ, 2019) as impaired due to *E. coli* bacteria. All of these segments were included in TMDL allocations.

Two more segments were listed as impaired due to *E. coli* bacteria in Virginia's 2020 305(b)/303(d) IR (VADEQ, 2020). These impairments on Dickey's Swamp and the Tidal Mattaponi River are shown in Table 1-1 but are not included in this report for TMDL allocations. All sources and land use within these new impairment watersheds were included in the analysis for this report; therefore, DEQ plans to address them through the nesting process in the 2022 Water Quality Assessment Integrated Report.

Figure 1-1 shows the general project area, which was delineated based on 6<sup>th</sup> order Hydrologic Units from the National Watershed Boundary Dataset (NWBD), which are identified by 12-digit Hydrologic Unit Codes (HUCs). Within the general project area, 13 TMDL watersheds were identified based on the drainage of the 12 impaired streams. Sections 1.3.2 through 1.3.14 provide descriptions of the impaired streams and their associated TMDL watersheds.

### 1.3.2 Aylett Creek (F23R-04-BAC)

DEQ first identified Aylett Creek as impaired for *E. coli* bacteria in the 2012 Integrated Report due to exceedances of the state's water quality criterion (VADEQ, 2013).

Beginning at the headwater of Aylett Creek, the impaired segment extends for 6.83 miles downstream to the confluence with the Mattaponi River. During the 2016 assessment period (January 1, 2009 through December 31, 2014), 3 of 11 samples (27.3%) exceeded the maximum water quality assessment criterion for *E. coli* bacteria (235 counts/100 ml)

at station 8-AYL002.27, which is located at Route 600. The TMDL watershed includes 10.5 acres in King and Queen County and 5446 acres in King William County.

#### 1.3.3 Courthouse Creek (F24R-03-BAC)

DEQ first identified this portion of Courthouse Creek as impaired for *E. coli* bacteria in the 2016 Integrated Report due to exceedances of the state's water quality criterion (VADEQ, 2018a). The impaired segment extends for 0.72 miles from King and Queen Courthouse Pond downstream to the tidal limit. During the 2016 assessment period 3 of 12 samples (25.0%) exceeded the maximum water quality assessment criterion for *E. coli* bacteria (235 counts/100 ml) at station 8-CTH001.96, which is located at Route 14. The TMDL watershed covers 5887 acres in King and Queen County.

#### 1.3.4 Dickey's Swamp (F23R-08-BAC)

DEQ first identified this portion of Dickey's Swamp as impaired for *E. coli* bacteria in the 2014 Integrated Report due to exceedances of the state's water quality criterion (VADEQ, 2016b). The impaired segment extends for 4.33 miles from Dogwood Fork downstream to the Route 620 bridge. During the 2014 assessment period, 4 of 12 samples (33.3%) exceeded the maximum water quality assessment criterion for *E. coli* bacteria (235 counts/100 ml) at station 8-DKW004.31, which is located at Route 620. The TMDL watershed covers 145.5 acres in Essex County and 9923 acres in King and Queen County.

#### 1.3.5 Dogwood Fork (F23R-11-BAC)

DEQ first identified this portion of Dogwood Fork as impaired for *E. coli* bacteria in the 2014 Integrated Report due to exceedances of the state's water quality criterion (VADEQ, 2016b). Beginning at the headwater of Dogwood Fork, the impaired segment extends for 2.91 miles downstream to the confluence with Dickey's Swamp. During the 2016 assessment period, 4 of 12 samples (33.3%) exceeded the maximum water quality assessment criterion for *E. coli* bacteria (235 counts/100 ml) at station 8-DWD000.77, which is located at Route 621. The TMDL watershed covers 1454 acres in King and Queen County.

#### 1.3.6 Dorrell Creek (F21R-08-BAC)

DEQ first identified this portion of Dorrell Creek as impaired for *E. coli* bacteria in the 2018 Integrated Report due to exceedances of the state's water quality criterion (VADEQ, 2019). Beginning at the confluence with Little Dorrell Creek, the impaired segment extends downstream for 4.96 miles to the confluence with Herring Creek. During the 2018 assessment period, 2 of 12 samples (16.7%) exceeded the maximum water quality assessment criterion for *E. coli* bacteria (235 counts/100 ml) at station 8-DRL000.85, which is located at Route 608. The TMDL watershed covers 1454 acres in King and Queen County.

#### 1.3.7 Garnetts Creek (F23R-01-BAC)

DEQ first identified this portion of Garnetts Creek as impaired for *E. coli* bacteria in the 2010 Integrated Report due to exceedances of the state's water quality criterion (VADEQ, 2011). The impaired segment extends for 2.83 miles from Dickey's Swamp downstream to the tidal limit. During the 2016 assessment period, 6 of 23 samples (26.1%) exceeded the maximum water quality assessment criterion for *E. coli* bacteria (235 counts/100 ml) at station 8-GNT001.54, which is located at Route 633. The TMDL watershed covers 1613 acres in King and Queen County.

#### 1.3.8 Gravel Run (F21R-09-BAC)

DEQ first identified Gravel Run as impaired for *E. coli* bacteria in the 2018 Integrated Report due to exceedances of the state's water quality criterion (VADEQ, 2019). Beginning at the perennial headwater of Gravel Run, the impaired segment extends for 3.54 miles downstream to the confluence with the Mattaponi River. During the 2018 assessment period, 5 of 12 samples (41.7%) exceeded the maximum water quality assessment criterion for *E. coli* bacteria (235 counts/100 ml) at station 8-GVL000.56, which is located at Route 628. The TMDL watershed covers 2693 acres in King and Queen County.

#### 1.3.9 Herring Creek (F21R-05-BAC)

DEQ first identified this portion of Herring Creek as impaired for *E. coli* bacteria in the 2016 Integrated Report due to exceedances of the state's water quality criterion (VADEQ, 2018a). The impaired segment extends for 5.09 miles from the confluence with Dorrell

Creek downstream to the confluence with an unnamed tributary to Herring Creek, at rivermile 2.14. During the 2016 assessment period, 2 of 12 samples (16.7%) exceeded the maximum water quality assessment criterion for *E. coli* bacteria (235 counts/100 ml) at station 8-HER005.12, which is located at Route 609. During the 2018 assessment period, the adjacent downstream segment of Herring Creek from the unnamed tributary downstream until the confluence with the Mattaponi River was also listed as impaired for *E. coli* bacteria. 4 of 24 (16.7%) samples exceeded the maximum criterion for *E. coli* at station 8-HER000.33, located at Route 600. This segment is 2.14 miles, making the total Herring Creek impairment 7.23 miles. The TMDL watershed covers 5692 acres in Caroline County and 17557 acres in King William County.

#### 1.3.10 Market Swamp (F23R-09-BAC)

DEQ first identified this portion of Market Swamp as impaired for *E. coli* bacteria in the 2014 Integrated Report due to exceedances of the state's water quality criterion (VADEQ, 2016b). The impaired segment extends for 2.01 miles from Walker Coleman Pond and extends to mouth at the confluence with Dickey's Swamp. During the 2016 assessment period, 2 of 12 samples (16.7%) exceeded the maximum water quality assessment criterion for *E. coli* bacteria (235 counts/100 ml) at station 8-MKT001.04, which is located at Route 14. The TMDL watershed covers 5897 acres in King and Queen County.

#### 1.3.11 Mattaponi River (F21R-06-BAC) (Non-tidal)

DEQ first identified this portion of the Mattaponi River as impaired for *E. coli* bacteria in the 2016 Integrated Report due to exceedances of the state's water quality criterion (VADEQ, 2018a). The impaired segment extends for 8.00 miles from the confluence with Maracossic Creek downstream to the confluence with Gravel Run. During the 2016 assessment period, 5 of 36 samples (13.9%) exceeded the maximum water quality assessment criterion for *E. coli* bacteria (235 counts/100 ml) at station 8-MPN054.17, which is located at Route 628. The TMDL watershed covers 3621 acres in King and Queen County and 3505 acres in King William County.

#### 1.3.12 Mattaponi River (F23E-02-BAC and F24E-02-BAC) (Tidal)

DEQ first identified this tidal portion of the Mattaponi River as impaired for *E. coli* bacteria in the 2016 Integrated Report due to exceedances of the state's water quality

criterion (VADEQ, 2018a). The impaired segment encompasses 1.756 square miles from Aylett Creek and downstream to Garnetts Creek. During the 2016 assessment period, 2 of 9 samples (22.2%) exceeded the maximum water quality assessment criterion for *E. coli* bacteria (235 counts/100 ml) at station 8-MPN034.33, which is located at the pier at Rosepoint. During the 2018 assessment period, the adjacent downstream portion of the Mattaponi River from Garnetts Creek to the tidal freshwater/oligohaline boundary at approximately river mile 18 was also listed as impaired for *E. coli* (VADEQ, 2019). Four of 35 (11.4%) samples exceeded the *E. coli* criterion at station 8-MPN017.46. This added 1.38 square miles of impaired area, for a total of 3.14 square miles of impaired tidal area. The TMDL watershed covers 29283 acres in King and Queen County and 22601 acres in King William County.

#### 1.3.13 XDN–Garnetts Creek, UT (F23R-12-BAC)

DEQ first identified this unnamed tributary (UT) to Garnetts Creek as impaired for *E. coli* bacteria in the 2016 Integrated Report due to exceedances of the state's water quality criterion (VADEQ, 2018a). Beginning at the headwater of this unnamed tributary, the impaired segment extends for 2.53 miles downstream to the confluence with Garnetts Creek. During the 2016 assessment period, 2 of 11 samples (18.2%) exceeded the maximum water quality assessment criterion for *E. coli* bacteria (235 counts/100 ml) at station 8-XDN000.12, which is located at Route 620. The TMDL watershed covers 1145 acres in King and Queen County.

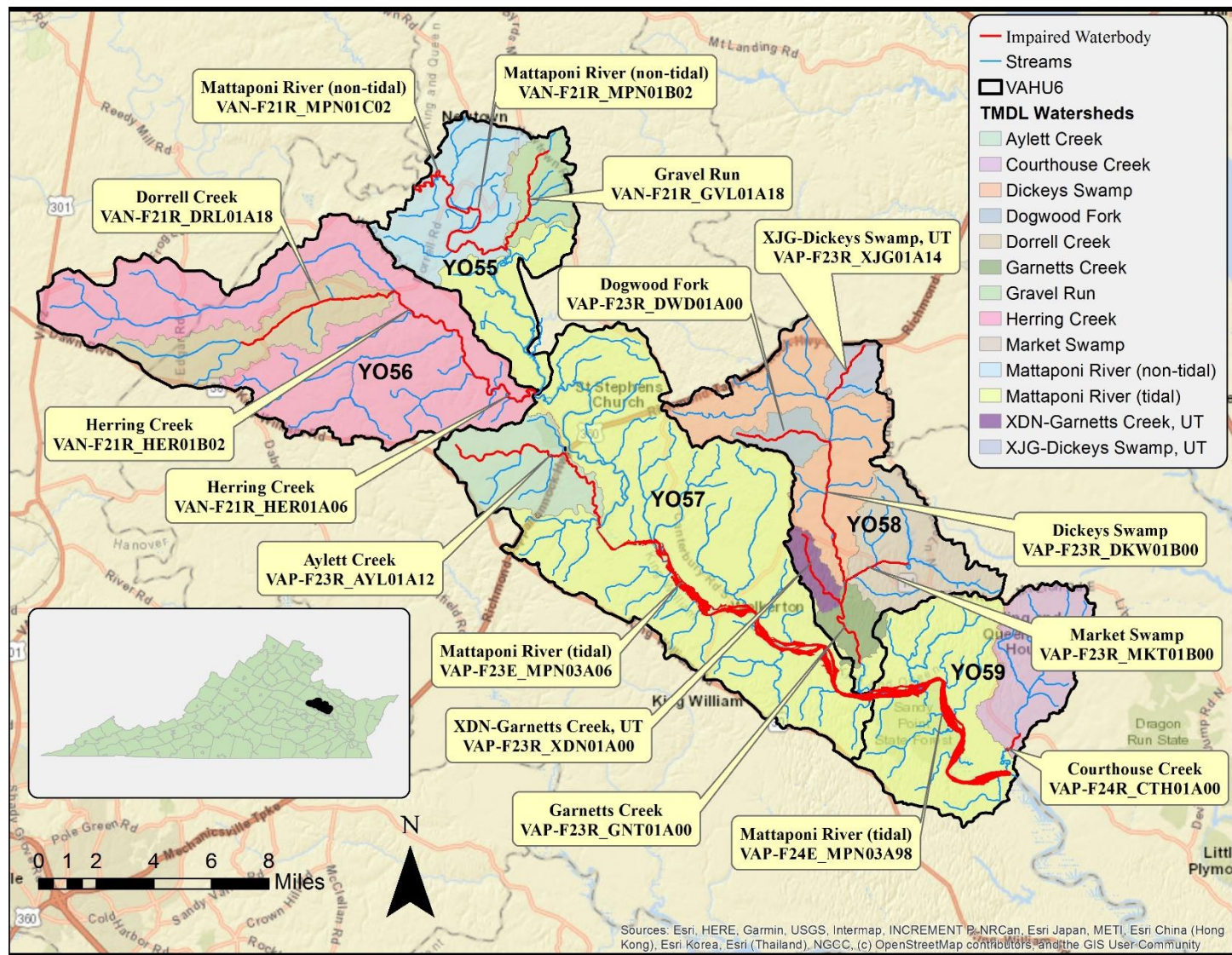
#### 1.3.14 XJG–Dickeys Swamp, UT (F23R-10-BAC)

DEQ first identified this unnamed tributary (UT) to Dickey's Swamp as impaired for *E. coli* bacteria in the 2014 Integrated Report due to exceedances of the state's water quality criterion (VADEQ, 2016b). Beginning at the headwaters of this unnamed tributary, the impaired segment extends for 1.99 miles downstream to the confluence with Dickey's Swamp. During the 2016 assessment period, 5 of 12 samples (41.7%) exceeded the maximum water quality assessment criterion for *E. coli* bacteria (235 counts/100 ml) at station 8-XJG000.08, which is located at a private road off of Route 621. The TMDL watershed covers 1236 acres in King and Queen County and 8.5 acres in Essex County.

*Table 1-1. Summary of stream segments impaired for E. coli bacteria in the project area (based on the 2016, 2018, and 2020 305(b)/303(d) Water Quality Assessment Integrated Reports)*

Water Name	Cause Group Code	305(b)/303(d) Assessment Unit ID	Year First Listed as Impaired	Impairment Size	County	Impairment Length Description
Aylett Creek	F23R-04-BAC	VAP-F23R_AYL01A12	2012	6.83 miles	King William	headwaters to mouth at Mattaponi River
Courthouse Creek	F24R-03-BAC	VAP-F24R_CTH01A00	2016	0.72 miles	King and Queen	extends from King and Queen Courthouse Pond downstream to the tidal limit
Dickeys Swamp	F23R-08-BAC	VAP-F23R_DKW01B00	2014	4.33 miles	King and Queen	Dogwood Fork to Route 620
Dickeys Swamp	F23R-13-BAC	VAP-F23R_DKW01A00	2020	3.99 miles	King and Queen	headwaters to Dogwood Fork
Dogwood Fork	F23R-11-BAC	VAP-F23R_DWD01A00	2014	2.91 miles	King and Queen	headwaters to its mouth at Dickeys Swamp
Dorrell Creek	F21R-08-BAC	VAN-F21R_DRL01A18	2018	4.96 miles	King William	confluence with Little Dorrell Creek downstream to the confluence with Herring Creek
Garnetts Creek	F23R-01-BAC	VAP-F23R_GNT01A00	2010	2.83 miles	King and Queen	extends from Dickeys Swamp to the tidal limit
Gravel Run	F21R-09-BAC	VAN-F21R_GVL01A18	2018	3.54 miles	King and Queen	perennial headwaters to the confluence with Mattaponi River
Herring Creek	F21R-05-BAC	VAN-F21R_HER01B02	2016	5.09 miles	King William	confluence with Dorrell Creek downstream until the confluence with an unnamed tributary to Herring Creek, at rivermile 2.14
Herring Creek	F21R-05-BAC	VAN-F21R_HER01A06	2018	2.14 miles	King William	confluence with an unnamed tributary to Herring Creek, at rivermile 2.14, downstream until the confluence with the Mattaponi River
Market Swamp	F23R-09-BAC	VAP-F23R_MKT01B00	2014	2.01 miles	King and Queen	Walker Coleman Pond to mouth at confluence with Dickeys Swamp
Mattaponi River (non-tidal)	F21R-06-BAC	VAN-F21R_MPN01C02 VAN-F21R_MPN01B02	2016	8.00 miles	King and Queen/ King William	confluence with Maracossic Creek downstream to the confluence with Gravel Run
Mattaponi River (tidal)	F23E-02-BAC	VAP-F23E_MPN03A06	2016	1.76 square miles	King and Queen/ King William	Aylett Creek to Garnetts Creek
Mattaponi River (tidal)	F24E-02-BAC	VAP-F24E_MPN03A98	2018	1.38 square miles	King and Queen/ King William	Garnetts Creek to tidal freshwater/oligohaline boundary at approximately river mile 18
Mattaponi River (tidal)	F24E-03-BAC	VAP-F23E_MPN02A98	2020	0.16 square miles	King and Queen/ King William	tidal limit above Route 360 bridge to the confluence with Aylett Creek
XDN-Garnetts Creek, UT	F23R-12-BAC	VAP-F23R_XDN01A00	2016	2.53 miles	King and Queen	headwaters to mouth at confluence with Garnetts Creek

Water Name	Cause Group Code	305(b)/303(d) Assessment Unit ID	Year First Listed as Impaired	Impairment Size	County	Impairment Length Description
XJG-Dickeys Swamp, UT	F23R-10-BAC	VAP-F23R_XJG01A14	2014	1.99 miles	King and Queen	headwaters to mouth at confluence with Dickeys Swamp



*Figure 1-1. Map of Stream Segments impaired for E. coli bacteria in the project area (based on the 2016 and 2018 305(b)/303(d) Water Quality Assessment Integrated Reports)*

## 2 WATERSHED CHARACTERIZATION

---

### 2.1 Selection of Subwatersheds

To account for the spatial distribution of pollutant sources, the lower Mattaponi River project area was subdivided into 98 subwatersheds as shown in Figure 2-1. The lower Mattaponi River freshwater streams, which include subwatersheds 1, 8, 260, 261 and 262, contribute to the impairment of the tidal segment. The stream network used to help define the subwatersheds was obtained from the National Hydrography Dataset. Subwatersheds were delineated based on a number of factors: continuity of the stream network, similarity of land use distribution, major bridge/culverts, and monitoring station locations. It is preferable to have a subwatershed outlet at or near monitoring station locations in order to calibrate the models chosen for this study (to be discussed in Sections 4 and 6).

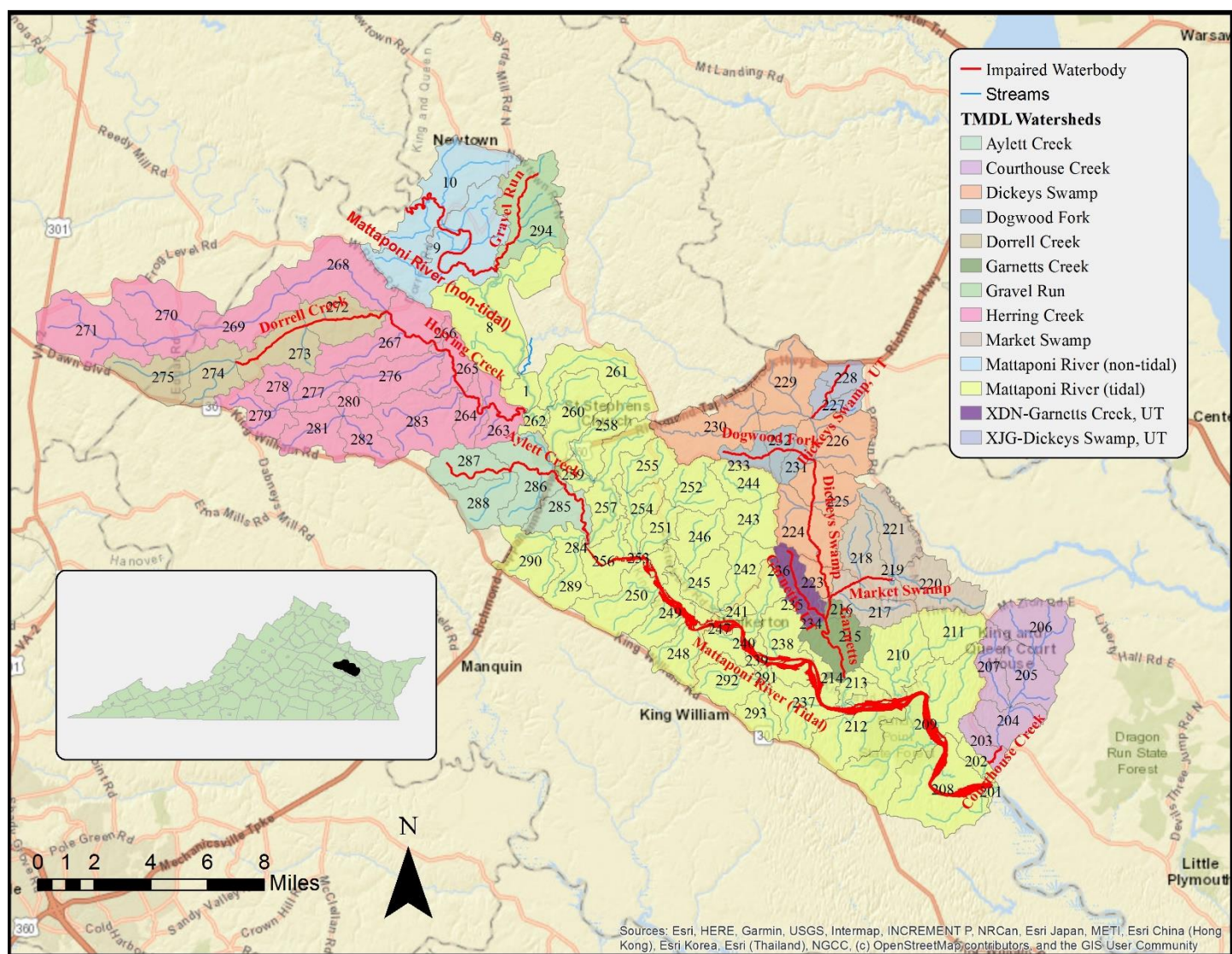


Figure 2-1. Impaired waterbodies and delineated subwatersheds within TMDL watersheds used in the assessment of watershed characteristics and pollutant sources

## 2.2 Water Resources, Ecoregion, Soils, and Climate

### 2.2.1 Water Resources

Virginia incorporates both “watershed” and “hydrologic units” as terms within TMDLs.

Hydrologic units are similar to watersheds, but are designed to act as a hierarchical system that groups drainage areas within each other. There are four federally-recognized levels. Virginia included a 5th and 6th order to break the drainage areas down smaller than 703 sq. miles to improve project planning and project effectiveness. The coding system for the VAHU5 and VAHU6 are only used within Virginia.

The lower Mattaponi River project area is part of the Mattaponi River subbasin (USGS HUC 02080105) (USGS, 2018). The lower Mattaponi River project area is located in Caroline, Essex, King and Queen, and King William Counties. Table 2-1 shows the acreage of TMDL watersheds in each county. The Mattaponi River generally flows southeast and discharges into the York River, which flows into the Chesapeake Bay.

*Table 2-1. Acreage of TMDL watersheds in applicable counties*

Watershed Name	Caroline County	Essex County	King and Queen County	King William County
Aylett Creek	0	0	0	5468.5
Courthouse Creek	0	0	5887.4	0
Dickeys Swamp	0	55.7	10013.0	0
Dogwood Fork	0	0	1454.4	0
Dorrell Creek	724.8	0	0	5167.6
Garnetts Creek	0	0	1613.3	0
Gravel Run	0	0	2693.1	0
Herring Creek	5542.4	0	0	18777.1
Market Swamp	0	0	5910.1	0
Mattaponi River	0	0	3963.7	3162.0
Mattaponi River, Tidal Segment	0	0	29283.1	22600.9
XDN-Garnetts Creek, UT	0	0	1144.9	0
XJG-Dickeys Swamp, UT	0	9.8	1234.6	0
<b>Total watershed acreage in county:</b>	<b>6267.2</b>	<b>65.5</b>	<b>63197.6</b>	<b>55176.1</b>
<b>Total county area:</b>	<b>219,840</b>	<b>164,970</b>	<b>344,768</b>	<b>174,144</b>
<b>Percent of county total acreage:</b>	<b>2.85%</b>	<b>0.04%</b>	<b>18.33%</b>	<b>31.68%</b>

### 2.2.2 Ecoregion

The lower Mattaponi River project area is located within the Rolling Coastal Plain of Southeastern Plains Ecoregion. The southeastern plain is composed of irregular plains that are covered by a mosaic of cropland, pasture, woodland, and forest. However, the Rolling Coastal Plain (65m) Ecoregion is a rolling, hilly, dissected portion of the Inner Coastal Plain that is made up of sedimentary material. Lithology is distinct from the adjacent Northern Outer Piedmont (45f) that is composed of metamorphic rocks. The terrain is hillier than the Chesapeake-Albemarle Silty Lowlands and Tidal Marshes (63b). Elevations typically range from 30 to 250 feet and local relief is 25 to 175 feet (7.6-53 m). Relief, elevation, and channel gradients are generally greater than in the Middle Atlantic Coastal Plain (63m); correspondingly, drainage also tends to be better. Stream margins can be swampy and stained water can occur. Parts of the Fall Zone are included in the westernmost portion of the Rolling Coastal Plain (65m); here aquatic habitats vary between the islands, pools, swampy streams, and cascades of the zone. The Fall Line acts as the western border and separates Ecoregion 65m from the higher and lithologically distinct Northern Outer Piedmont (45f). Its eastern limit is the Suffolk and Harpersville scarps which separate it from the low, flat terraces of Ecoregion 63b. Its southeastern boundary is the Surry Scarp that divides it from the middle-elevation terraces of Ecoregion 63e. Ecoregion 65m's northern border with the Chesapeake Rolling Coastal Plain (65n) is the Potomac River where forest density and soil temperature regimes change (USEPA, 1999b).

The Rolling Coastal Plain (65m) Ecoregion is a mosaic of woodland and farmland (USDA-NRCS, 2015). Common crops are corn, soybeans, and, in the south, peanuts. Hardwoods are now more common than at the time of settlement because of frequent fires and the repeated preferential cutting of pine. Woodlands are more extensive than in the Northern Rolling Inner Coastal Plain (65n) to the north of the Potomac River.

### 2.2.3 Soils

The State Soil Geographic Data (SSURGO) soils data were used for the purpose of characterizing the soils in the study watersheds (USDA-2019, 2019). Table 2-2 and Figure 2-2 show the distribution of soils by soil name within the project area. Hydrologic soil groups were primarily considered for this characterization, and describe soil texture in terms of potential for surface runoff and infiltration rates, as shown in Table 2-3 and Table 2-4. For example, soils in

hydrologic group “A” pass a larger proportion of rainfall through to ground water than soils in hydrologic group “B.” Conversely, soils in hydrologic group “D” inhibit infiltration such that a large proportion of rainfall contributes to surface runoff and therefore a more direct path to stream channels. These processes have consequences for bacteria residing on the land surface in terms of the potential bacteria loads transported to streams during storm events. Hydrologic soil group B, which includes silt loam or loam soils with moderately fine to moderately coarse textures and a moderate infiltration rate when thoroughly wetted, represent the highest percentage (58%) in the lower Mattaponi River project area.

*Table 2-2. Distribution of soils in the project area*

Soil Name	Soil Group	Acres	Percent of Project Area	Soil Name	Soil Group	Acres	Percent of Project Area
Altavista	C	282	<1%	Myatt	B/D	11206	9%
Atlee	C	1	<1%	Nevarc	D	13	<1%
Bama	B	1416	1%	Osier	A/D	643	1%
Bibb	B/D	3736	3%	Pits, gravel	Undefined	108	<1%
Bohicket	D	211	<1%	Rappahannock	B/D	4498	4%
Bojac	A	2073	2%	Roanoke	C/D	3633	3%
Chastain	C/D	355	<1%	Rumford	A	6786	5%
Conetoe	A	566	<1%	Seabrook	A	1812	1%
Craven	D	555	<1%	Slagle	C	2590	2%
Emporia	B	13530	11%	State	B	2824	2%
Emporia	C	4335	3%	Suffolk	B	4404	4%
Kempsville	B	5527	4%	Tarboro	A	4833	4%
Kenansville	A	126	<1%	Tetotum	C	2295	2%
Kinston	B/D	34770	28%	Tomotley	B/D	4205	3%
Levy	C/D	876	1%	Udorthents	Undefined	168	<1%
Mattan	B/D	576	<1%	Water	Undefined	3007	2%
Mattaponi	C	219	<1%	Wehadkee	B/D	1823	1%
Munden	B	705	1%				
				Grand Total		124,706	100%

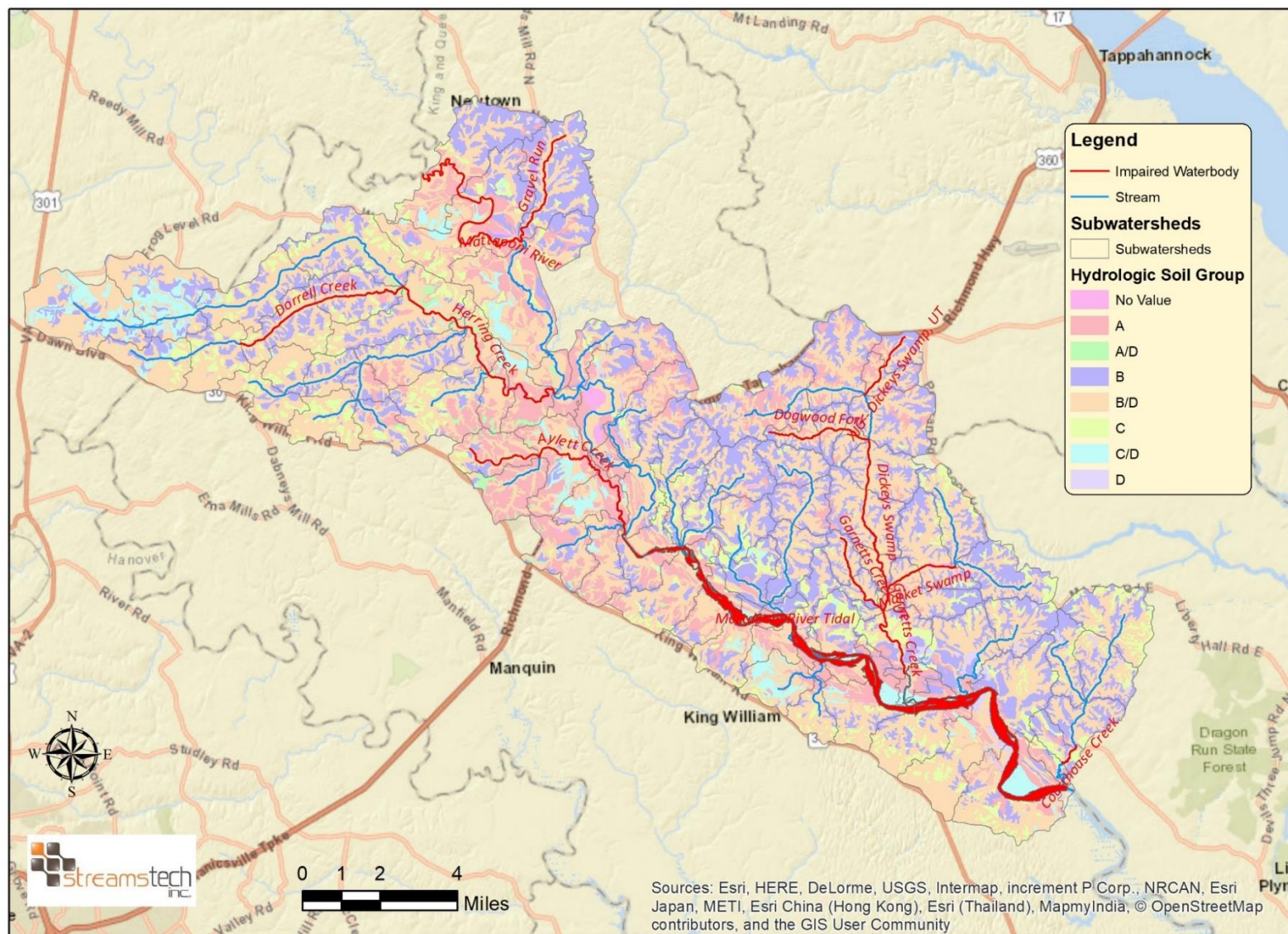
*Table 2-3. Hydrologic soil group descriptions*

Hydrologic Soil Group	Description
A	High infiltration rates. Soils are deep, well drained to excessively drained sand and gravels.
B	Moderate infiltration rates. Deep and moderately deep, moderately to well-drained soils with moderately coarse textures.
C	Moderate to slow infiltration rates. Soils with layers impeding downward movement of water or soils with moderately fine or fine textures.
D	Very slow infiltration rates. Soils are clayey, have high water table, or shallow to an impervious cover.
A/D	Combination of Hydrologic Soil Groups A and D, where drained areas are of Soil Group A and undrained areas are of Group D.
B/D	Combination of Hydrologic Soil Groups B and D, where drained areas are of Soil Group B and undrained areas are of Group D.
C/D	Combination of Hydrologic Soil Groups C and D, where drained areas are of Soil Group C and undrained areas are of Group D.

Table 2-4. Distribution of hydrologic soil groups in the project area

TMDL Watershed	Area	Undefined Soil Group	Soil Group A	Soil Group A/D	Soil Group B	Soil Group B/D	Soil Group C	Soil Group C/D	Soil Group D	Total*
Aylett Creek	Acres	51.1	597.5	10.4	2901.1	966.8	822.1	119.5	0.0	5468.5
	% Total	0.9%	10.9%	0.2%	53.1%	17.7%	15.0%	2.2%	0.0%	100.0%
Courthouse Creek	Acres	28.2	76.6	0.0	4290.9	391.4	966.6	10.0	123.7	5887.4
	% Total	0.5%	1.3%	0.0%	72.9%	6.6%	16.4%	0.2%	2.1%	100.0%
Dickeys Swamp	Acres	67.3	1097.3	0.0	8166.0	422.3	129.6	163.7	22.6	10068.7
	% Total	0.7%	10.9%	0.0%	81.1%	4.2%	1.3%	1.6%	0.2%	100.0%
Dogwood Fork	Acres	15.0	123.6	0.0	1252.2	38.0	25.7	0.0	0.0	1454.4
	% Total	1.0%	8.5%	0.0%	86.1%	2.6%	1.8%	0.0%	0.0%	100.0%
Dorrell Creek	Acres	12.8	31.3	0.0	3252.1	506.8	1893.6	196.0	0.0	5892.4
	% Total	0.2%	0.5%	0.0%	55.2%	8.6%	32.1%	3.3%	0.0%	100.0%
Garnetts Creek	Acres	8.6	176.4	0.0	765.1	201.9	380.4	34.3	46.7	1613.3
	% Total	0.5%	10.9%	0.0%	47.4%	12.5%	23.6%	2.1%	2.9%	100.0%
Gravel Run	Acres	3.9	54.9	0.0	2384.6	118.4	100.2	0.0	31.2	2693.1
	% Total	0.1%	2.0%	0.0%	88.5%	4.4%	3.7%	0.0%	1.2%	100.0%
Herring Creek	Acres	88.6	552.5	19.9	13995.2	2553.9	5803.7	222.2	12.9	23248.8
	% Total	0.4%	2.4%	0.1%	60.2%	11.0%	25.0%	1.0%	0.1%	100.0%
Market Swamp	Acres	172.6	60.9	0.0	4832.4	146.0	677.3	0.7	20.3	5910.1
	% Total	2.9%	1.0%	0.0%	81.8%	2.5%	11.5%	0.0%	0.3%	100.0%
Mattaponi River	Acres	86.4	1270.7	26.7	3311.2	1353.9	1021.7	31.8	23.3	7125.7
	% Total	1.2%	17.8%	0.4%	46.5%	19.0%	14.3%	0.4%	0.3%	100.0%
Mattaponi River, Tidal Segment	Acres	2741.6	7845.0	512.5	25611.4	7741.9	7556.6	660.3	285.3	52954.6
	% Total	5.2%	14.8%	1.0%	48.4%	14.6%	14.3%	1.2%	0.5%	100.0%
XDN-Garnetts Creek, UT	Acres	0.0	17.5	0.0	974.0	66.3	73.9	13.1	0.0	1144.9
	% Total	0.0%	1.5%	0.0%	85.1%	5.8%	6.5%	1.1%	0.0%	100.0%
XJG-Dickeys Swamp, UT	Acres	8.9	201.3	0.0	994.0	37.8	0.0	0.0	2.3	1244.4
	% Total	0.7%	16.2%	0.0%	79.9%	3.0%	0.0%	0.0%	0.2%	100.0%

\*\*Minor discrepancies in total areas for the TMDL Watersheds compared to other parts of this report are due to imperfections of the clipping function in ArcGIS and rounding



#### 2.2.4 Climate

Climatic data are available from the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC) website. The climate of the study watersheds was characterized based on the meteorological observations acquired from the Walkerton 2 NW station (USC00448829) located near Walkerton, Virginia and approximately 9.50 miles east from VA State Route 360 (Table 2-5). This station provides daily summaries of historical data through their Global Historical Climatology Network Daily (GHCND) database that includes various data elements such as temperature, precipitation, snow, evaporation, wind movement, cloudiness, etc. Figure 2-3 shows the location of this station within the project area.

The average daily temperature is 57.4°F, where the highest daily average temperature of 97.5°F occurred in July and the lowest daily average temperature of 4°F occurred in January. This temperature data was obtained from climate normal data for the period of 2000-2018. However, the average of daily maximum temperatures in July was 87.5°F and the average daily minimum temperatures in January was 26.7°F. The precipitation data from this station was insufficient for hydrologic and water quality modeling. Therefore Tropical Rainfall Measurement Mission (TRMM) was used. Based on the TRMM data, average annual precipitation from 1998 to 2018 was 46.9 inches in the lower Mattaponi River project area.

It should be noted that extreme weather events such as hurricanes, which release abnormally large quantities of precipitation, can result in skewed hydrology model outputs and calibrations if the extreme observed precipitation data is input into the model. Such potential issues are avoided by selecting model calibration and validation years in which extreme weather events did not occur.

Table 2-5. Daily summary climatic station in the project area (NCDC, 2019)

Station ID	Name	Elevation (m)	Latitude	Longitude	Begin date	End date
GHCND:USC00448829	WALKERTON 2 NW VA US	11.9	37.733	-77.017	7/1/1932	11/29/2018

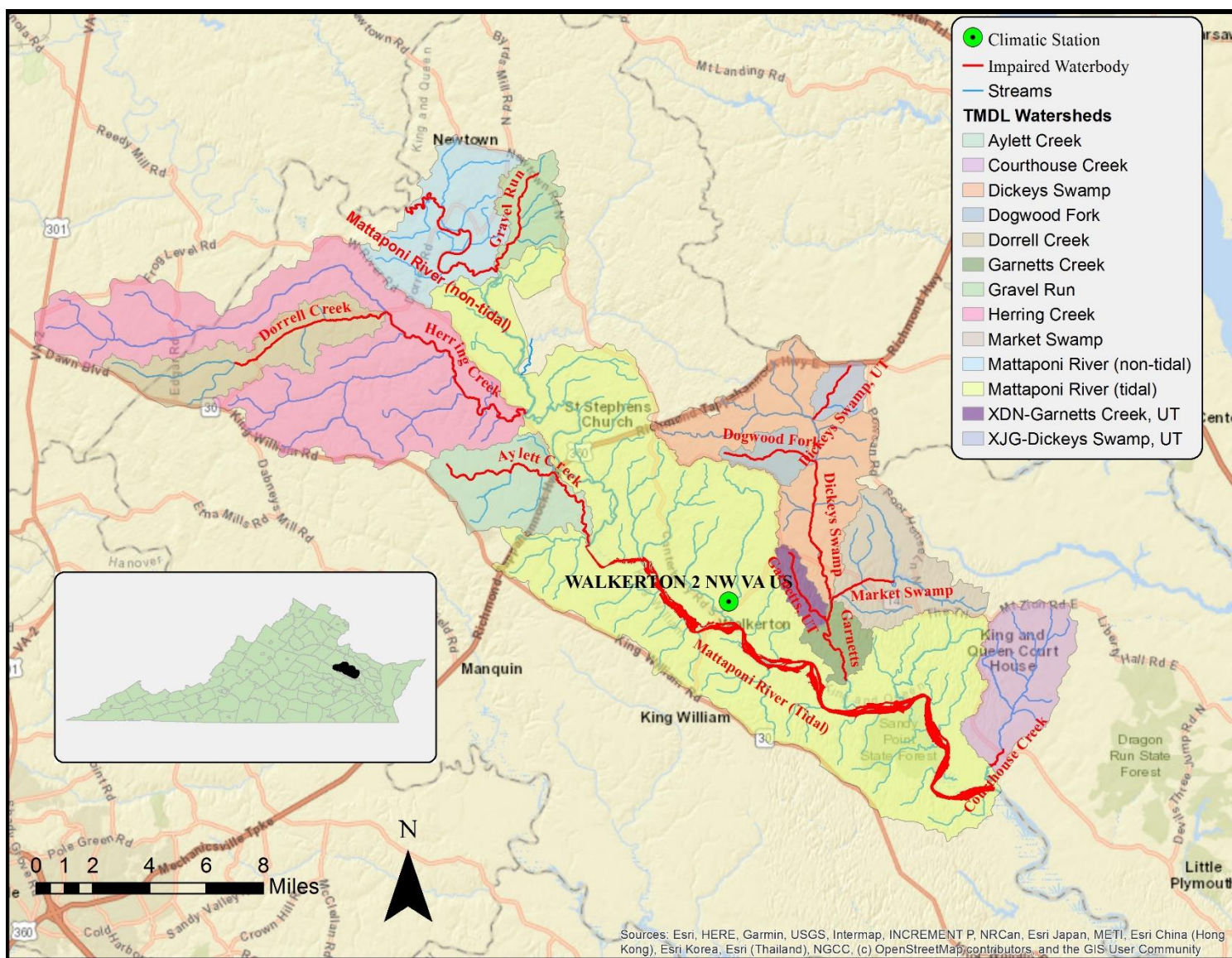


Figure 2-3. NCDC climatic station in the project area

## 2.3 Land Use

To develop the bacteria TMDLs, the 2017 National Agricultural Statistics Service (NASS) land use data, which includes National Land Cover Database (NLCD) 2011 land use data, were used to characterize land use in the project area (NLCD, 2011). Stakeholder input and aerial photos were used to verify land use characterization, and were used to adjust cropland area estimates as necessary. The land cover categories in the lower Mattaponi River project area were grouped into 10 major categories based on similarities in hydrologic features and waste application/production practices (Table 2-6). The land use categories were assigned pervious and impervious percentages for use in the watershed models. Land uses for the lower Mattaponi River project area are tabulated in Table 2-6 and presented graphically in Figure 2-4. Table 2-7 describes each land use.

Table 2-6. Land use distribution within the TMDL watersheds

TMDL Watershed	Area	Barren Land	Cropland	Developed, High Intensity	Developed, Low Intensity	Developed, Medium Intensity	Developed, Open Space	Forest	Hay*	Pasture	Water/Wetland	Total**
Aylett Creek	Acres	11.13	645.01	1.11	64.32	17.76	318.28	3582.30	9.12	374.20	445.28	5468.52
	% Total	0.20%	11.79%	0.02%	1.18%	0.32%	5.82%	65.51%	0.17%	6.84%	8.14%	100.00%
Courthouse Creek	Acres	3.12	272.79	0.22	20.40	4.23	165.19	4648.57	16.22	236.45	520.24	5887.42
	% Total	0.05%	4.63%	0.00%	0.35%	0.07%	2.81%	78.96%	0.28%	4.02%	8.84%	100.00%
Dickeys Swamp	Acres	62.53	1413.77	0.82	67.54	13.67	343.99	6537.20	62.65	689.32	877.22	10068.71
	% Total	0.62%	14.04%	0.01%	0.67%	0.14%	3.42%	64.93%	0.62%	6.85%	8.71%	100.00%
Dogwood Fork	Acres	0.00	257.82	0.00	2.83	0.22	46.01	947.07	12.24	103.76	84.43	1454.39
	% Total	0.00%	17.73%	0.00%	0.19%	0.02%	3.16%	65.12%	0.84%	7.13%	5.80%	100.00%
Dorrell Creek	Acres	28.55	823.28	0.00	14.96	0.27	163.05	3944.66	14.85	373.61	529.21	5892.44
	% Total	0.48%	13.97%	0.00%	0.25%	0.00%	2.77%	66.94%	0.25%	6.34%	8.98%	100.00%
Garnetts Creek	Acres	14.91	355.64	0.00	0.23	0.00	42.28	823.78	1.13	54.17	321.19	1613.33
	% Total	0.92%	22.04%	0.00%	0.01%	0.00%	2.62%	51.06%	0.07%	3.36%	19.91%	100.00%
Gravel Run	Acres	0.00	668.42	0.00	2.48	0.00	90.94	1312.80	7.57	526.27	84.64	2693.11
	% Total	0.00%	24.82%	0.00%	0.09%	0.00%	3.38%	48.75%	0.28%	19.54%	3.14%	100.00%
Herring Creek	Acres	61.19	2380.28	0.00	43.76	3.34	690.88	15705.90	82.81	1500.00	2780.69	23248.84
	% Total	0.26%	10.24%	0.00%	0.19%	0.01%	2.97%	67.56%	0.36%	6.45%	11.96%	100.00%
Market Swamp	Acres	14.71	322.68	0.00	13.63	0.22	129.42	4637.06	46.85	267.67	477.85	5910.09
	% Total	0.25%	5.46%	0.00%	0.23%	0.00%	2.19%	78.46%	0.79%	4.53%	8.09%	100.00%
Mattaponi River	Acres	9.21	1245.60	0.00	5.21	0.00	196.57	3620.91	7.45	750.81	1289.90	7125.65
	% Total	0.13%	17.48%	0.00%	0.07%	0.00%	2.76%	50.82%	0.10%	10.54%	18.10%	100.00%
Mattaponi River, Tidal	Acres	61.11	8499.55	5.43	174.10	44.57	1839.47	28564.67	162.06	3725.16	9878.52	52954.63
	% Total	0.12%	16.05%	0.01%	0.33%	0.08%	3.47%	53.94%	0.31%	7.03%	18.65%	100.00%
XDN-Garnetts Creek, UT	Acres	0.00	90.58	0.00	0.74	0.20	25.42	790.17	3.98	153.96	79.86	1144.90
	% Total	0.00%	7.91%	0.00%	0.06%	0.02%	2.22%	69.02%	0.35%	13.45%	6.98%	100.00%
XJG-Dickeys Swamp, UT	Acres	0.00	224.94	2.29	23.74	9.30	24.74	834.42	6.32	48.59	70.05	1244.39
	% Total	0.00%	18.08%	0.18%	1.91%	0.75%	1.99%	67.05%	0.51%	3.90%	5.63%	100.00%

\*Hay was separated from the pasture of NLCD 2011 data based on the National Agricultural Statistics Service (USDA-NASS, 2013) information

\*\*Minor discrepancies in total areas for the TMDL Watersheds compared to other parts of this report are due to imperfections of the clipping function in ArcGIS and rounding

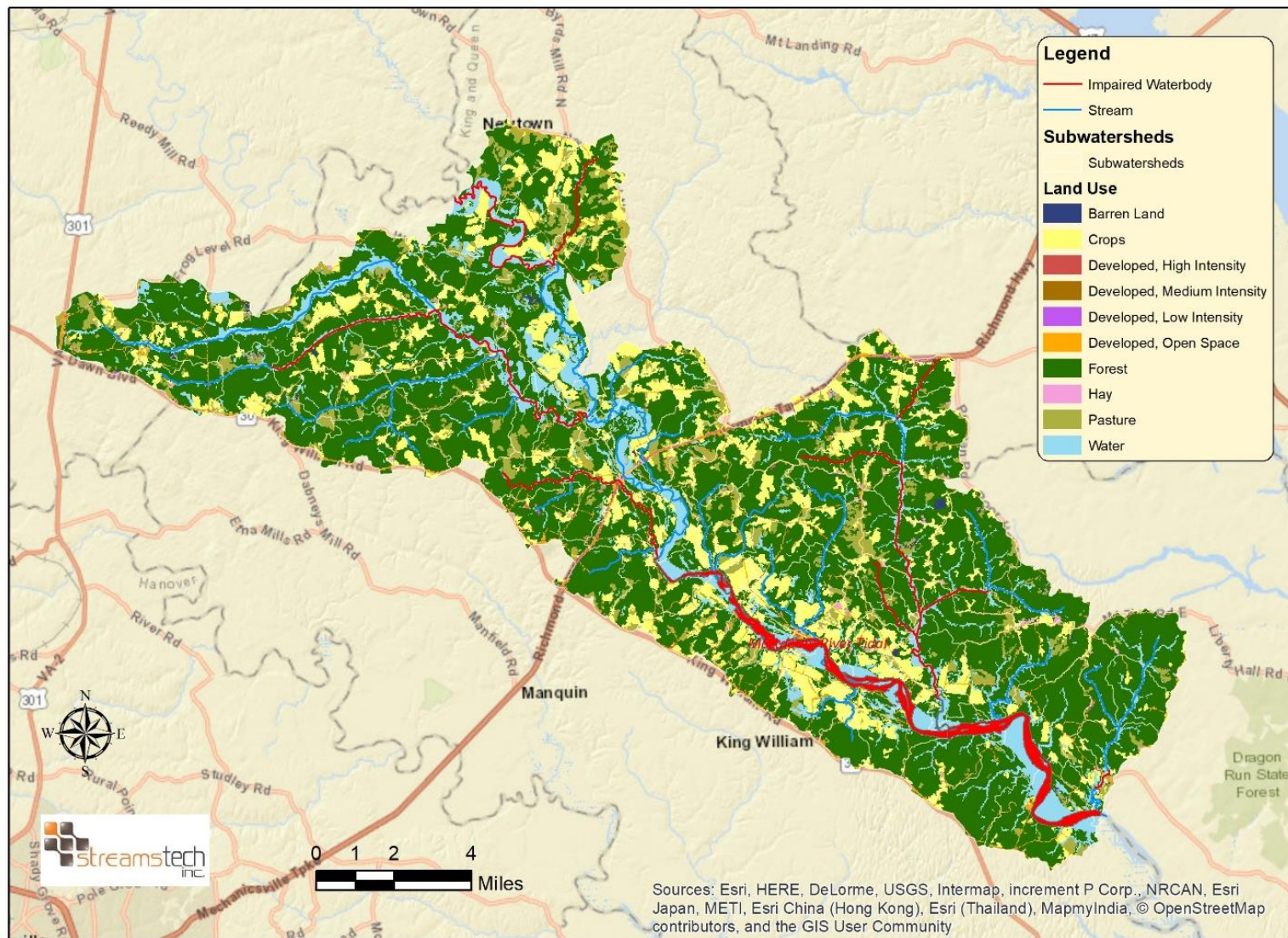


Figure 2-4. Land use distribution within the project area

*Table 2-7. Land use descriptions*

Land use Name	Description
Open Water	Areas of open water, generally with less than 25% cover of vegetation or soil.
Developed, Open Space	Areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
Developed, Low Intensity	Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
Developed, Medium Intensity	Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
Developed High Intensity	Highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
Barren Land (Rock/Sand/Clay)	Areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Deciduous Forest	Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
Evergreen Forest	Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
Mixed Forest	Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
Shrub/Scrub	Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
Grassland/Herbaceous	Areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
Pasture/Hay	Areas of grasses, legumes, or grass legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
Cultivated Crops	Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
Woody Wetlands	Areas where forest or shrub-land vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
Emergent Herbaceous Wetlands.	Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

## 2.4 Stream Flow Data

The United States Geological Survey (USGS) collects stream flow information statewide, and DEQ utilizes information from gages and special monitoring studies to support TMDL development. DEQ also has a special team that can collect stream flow information as needed for model calibration if there are no available USGS gages within the project area.

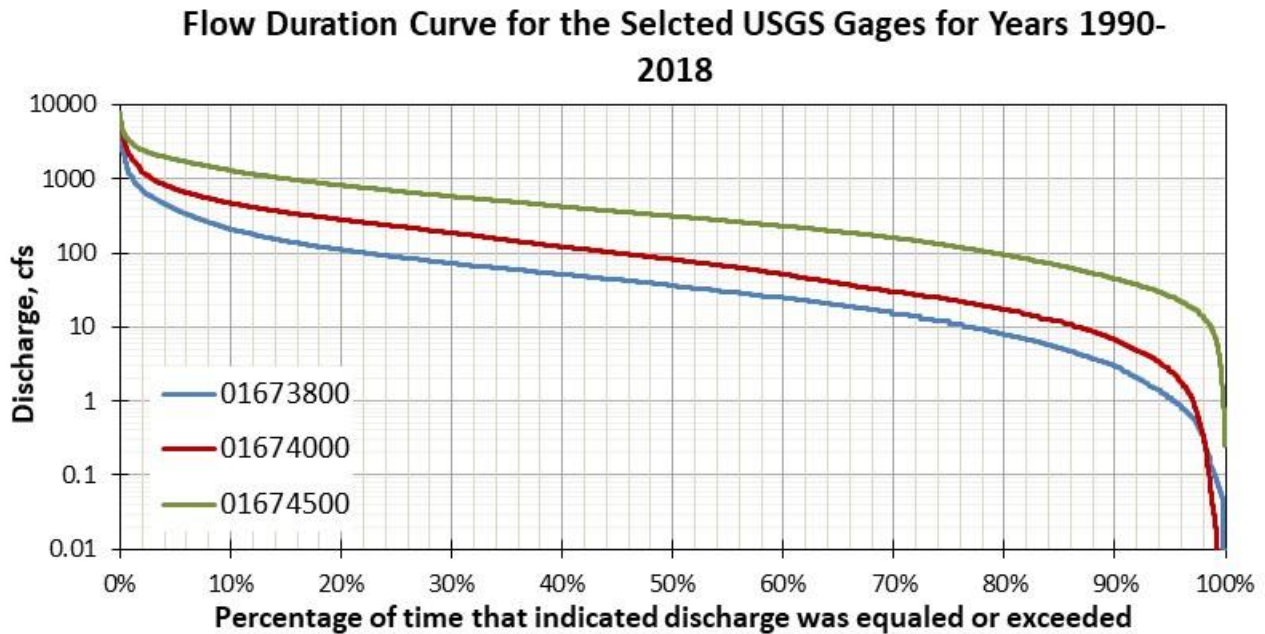
Three United States Geological Survey (USGS) flow gages with sufficient flow data are located within the Mattaponi River subbasin (USGS, 2019). The first station is near Spotsylvania, Virginia, along the Po River. The other two stations are along the Mattaponi River, one near Bowling Green and the other near Beulahville. Table 2-8 provide details about their characteristics and locations. Daily, seasonal and long-term stream flow characteristics can be determined by analyzing the data from these gaging stations. Figure 2-5 shows the flow duration curves at these gages using the data from 1990 through 2018. A flow duration curve shows the percentage of time a specific flow is equaled or exceeded during the analysis period. It gives a quick view of the magnitude, the range, and the temporal distribution of flow at a gage.

*Table 2-8. USGS stream flow gages and associated characteristics used for this TMDL*

Station ID	Station Name	Drainage area (Sq. Miles)	Elevation (feet, NGVD29)	Begin Date	End Date	Average Flow* (cfs)
01673800	Po River Near Spotsylvania, VA	77.6	183.76	10/1/1962	Present**	72.79
01674000	Mattaponi River Near Bowling Green, VA	256	84.33	10/1/1942	Present**	221.04
01674500	Mattaponi River Near Beulahville, VA	603	11.47	9/19/1941	Present**	514.34

\* Cubic feet per second during the period between January 1, 1990 and December 31, 2018

\*\* Last checked on March, 2019



*Figure 2-5. Flow duration curves for three USGS gaging stations using data from 1990 through 2018*

## 2.5 Water Quality Monitoring Data

DEQ has a long history of water quality monitoring. Each region has dedicated staff that collect water quality samples and field parameters throughout the year in Virginia's lakes/reservoirs, rivers, and estuaries. Over the years, the focus of monitoring has been guided by various regulatory and assessment needs. Since 1999, the agency has encouraged citizen water quality monitoring by providing technical and, whenever possible, financial support. In addition to support for citizen monitoring, the agency has been actively attempting to expand our partnerships with an increasing number of other water quality monitoring programs that operate independently of DEQ. By broadening the scope of data solicitation beyond citizen monitoring, DEQ is receiving water quality data from an expanding pool of government, private industry, and other non-citizen volunteer based monitoring organizations. (VADEQ, 2019)

The only data collected outside of DEQ used for this project were collected by USGS. DEQ provided the majority of instream water quality data; however, some of the samples for station 8-MPN054.14 were collected by the USGS. Data were collected and assessed from 24 stations

(listed in Table 2-9), which included bacteria data for this TMDL study. The 15 stations listed in Table 2-10 were used as impairment listing stations during the 2016 assessment period (2009 through 2014) and 2018 assessment period (2011 through 2016) due to samples exceeding the maximum water quality assessment criterion of 235 counts/100 ml for *E. coli* (Table 2-10 and Figure 2-6). The assessments were based on the WQS in place prior to the updated 2019 WQS.

*Table 2-9. DEQ bacteria monitoring stations in project area with samples collected during 2000 through 2018*

Stream Name	Station ID	Station Description	Sampling Period Start	Sampling Period End
Aylett Creek	8-AYL002.27	Aylett Creek at Rt. 600	1/6/2009	12/20/2017
Chapel Creek	8-CPL004.15	Newtown Rd, Rt. 721	2/11/2004	12/12/2016
Courthouse Creek	8-CTH001.96	Courthouse Creek, Rt. 14	7/16/2003	12/10/2014
Dickeys Swamp	8-DKW000.12	Dickeys Swamp, Rt. 620 Bridge	2/16/2000	12/20/2017
Dickeys Swamp	8-DKW001.12	Dickeys Swamp, Rt. 14	1/24/2011	12/14/2011
Dickeys Swamp	8-DKW004.31	Dickeys Swamp, Rt. 631	1/24/2011	12/20/2017
Dickeys Swamp	8-DKW005.73	Dickeys Swamp, Rt. 621	1/24/2011	12/20/2017
Dogwood Fork	8-DWD000.77	Dogwood Fork, Rt. 621	1/24/2011	12/20/2017
Dorrell Creek	8-DRL000.85	Locust Hill Rd, Rt. 608	1/6/2016	12/12/2016
Garnetts Creek	8-GNT001.54	Garnetts Creek, Rt. 633	6/6/2001	12/20/2017
Gravel Run	8-GVL000.56	Spring Cottage Rd, Rt. 628	1/6/2016	12/12/2016
Herring Creek	8-HER005.12	Smokey Rd, Rt. 609	2/16/2000	12/10/2014
Herring Creek	8-HER000.33	West River Rd, Rt. 600	1/23/2014	12/12/2016
Market Swamp	8-MKT001.04	Market Swamp, Rt. 14	1/24/2011	12/20/2017
Market Swamp	8-MKT001.96	DGIF Rd below W Coleman Pond	1/24/2011	12/14/2011
Mattaponi River, Tidal Segment	8-MPN017.46	Rt. 640, Wakema	2/16/2000	11/14/2018
Mattaponi River	8-MPN026.57	S of channel, E of Horse Landing	7/16/2013	7/16/2013
Mattaponi River	8-MPN028.78	S shore shallow water, Walkerton Bridge	7/1/2014	7/1/2014
Mattaponi River	8-MPN029.08	Rt. 629 Bridge At Walkerton	2/8/2000	4/26/2018
Mattaponi River	8-MPN034.33	Pier at Rosespoint	1/23/2014	12/10/2014
Mattaponi River	8-MPN045.51	6.9 RM upstream from Rt. 360	9/26/2013	9/26/2013
Mattaponi River	8-MPN054.17*	Spring Cottage Rd, Rt. 628	2/8/2000	4/19/2018
XDN-Garnetts Creek, UT	8-XDN000.12	RM 3.66, Rt 620	1/24/2011	12/20/2017
XJG -Dickeys Swamp, UT	8-XJG000.08	Private Rd off Rt 621	1/24/2011	12/14/2011

\* bacteria data for this station for this time period were collected by DEQ and USGS

*Table 2-10. Summary of instream E. coli bacteria monitoring data for the DEQ stations used for project area impairment listings during the 2016 (2009 through 2014) or 2018 (2011 through 2016) assessment periods*

Stream Name	Station ID	Assessment Period	Sample Count	Min (counts/100 ml)	Max (counts/100 ml)	Avg (counts/100 ml)	Percent Exceedance of Maximum Assessment Criterion (235 counts/100 ml)
Aylett Creek	8-AYL002.27	2016	11	25	900	217	27.3
Courthouse Creek	8-CTH001.96	2016	12	10	1600	247	25.0
Dickeys Swamp	8-DKW004.31	2016	12	25	750	198	25.0
Dogwood Fork	8-DWD000.77	2016	12	25	2000	323	33.3
Dorrell Creek	8-DRL000.85	2018	12	10	884	177	16.7
Garnetts Creek	8-GNT001.54	2016	12	25	900	240	33.3
Gravel Run	8-GVL000.56	2018	12	20	1137	288	41.7
Herring Creek	8-HER000.33	2018	24	20	800	160	16.7
	8-HER005.12	2016	12	41	644	158	16.7
Market Swamp	8-MKT001.04	2016	12	25	375	99	16.7
Mattaponi River	8-MPN054.17*	2016	36	20	1450	147	13.9
Mattaponi River, Tidal Segment	8-MPN017.46	2018	35	10	2481	159	11.4
	8-MPN034.33	2016	9	100	300	158	22.2
XDN-Garnetts Creek, UT	8-XDN000.12	2016	11	25	1375	239	18.2
XJG-Dickeys Swamp, UT	8-XJG000.08	2016	12	25	925	293	41.7

\* bacteria data for this station for this time period were collected by USGS

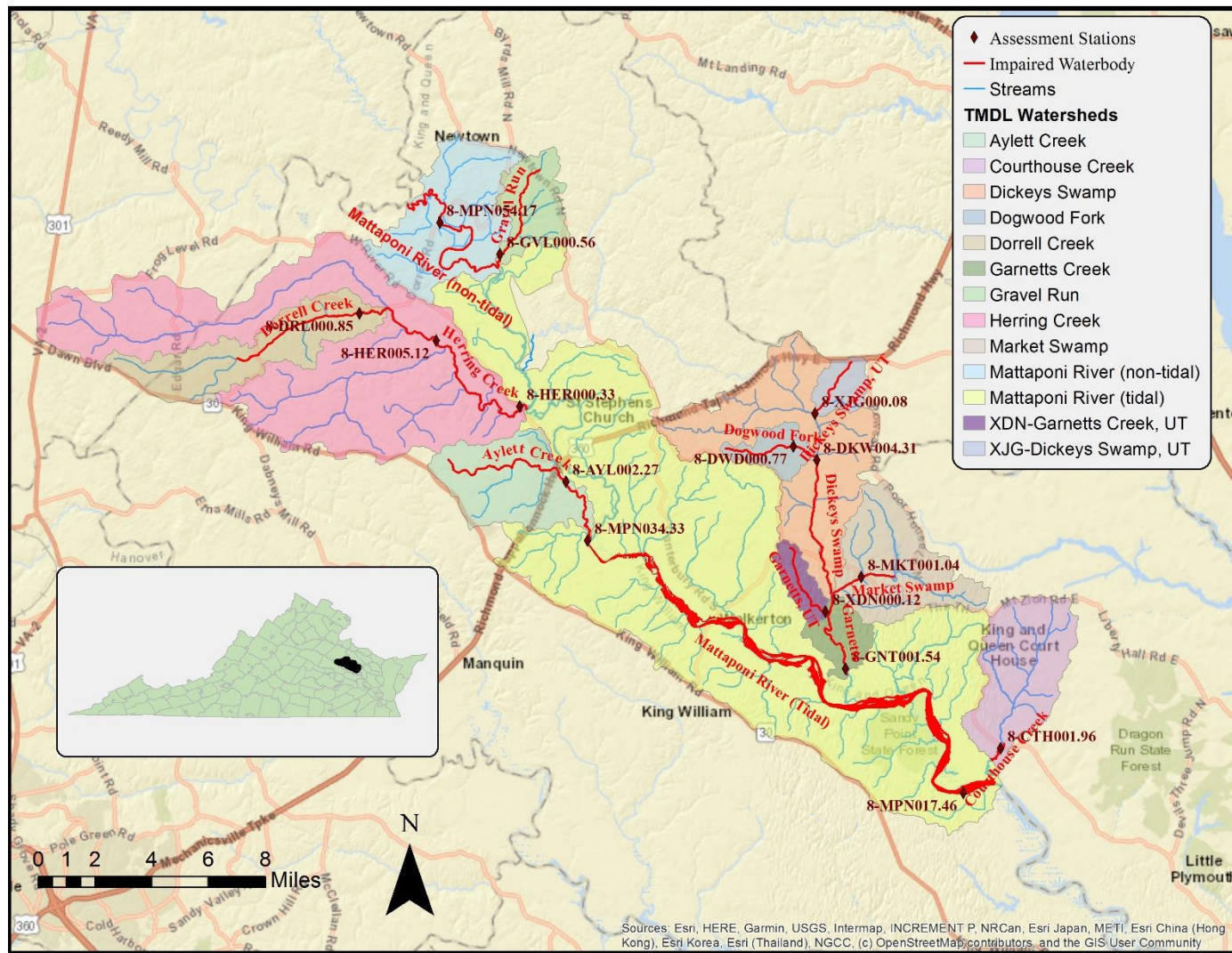


Figure 2-6. DEQ water quality monitoring stations and segments assessed as impaired for the recreational use due to exceedances of *E. coli* bacteria in the 2016 and 2018 Integrated Reports (VADEQ, 2018 and 2019)

### 3 POLLUTANT SOURCES

---

The sources of bacteria that may contaminate surface water include wastewater discharges, direct deposition from animal and human sources, and contaminated runoff. For the purpose of developing a TMDL, pollutant sources are generally classified as point and nonpoint sources. According to section 502(14) of the Clean Water Act, the term "point source" means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. This term does not include agricultural storm water discharges and return flows from irrigated agriculture. Nonpoint source pollution includes any source that does not meet the above legal definition of "point source" and includes pollutants from various sources over relatively large land areas. For the purposes of this TMDL, discharges from activities that do not have an associated National Pollutant Discharge Elimination System (NPDES) permit, such as failing septic systems and straight pipes, are considered nonpoint sources. The decision to assign load allocations (LAs) to those sources does not reflect a determination by DEQ as to whether they are, in fact, non-permitted point source discharges. Likewise, by establishing these TMDLs with failing septic systems and straight pipes treated as nonpoint sources, DEQ is not determining that such discharges are exempt from NPDES permitting requirements. The bacteria sources considered for this project are described in sections 3.13.1 and 3.2 below.

#### 3.1 Permitted Point Sources

##### 3.1.1 VPDES Permits

Virginia administers NPDES permits through the Virginia Pollutant Discharge Elimination System (VPDES) program. The discharge of pollutants from point sources is regulated through VPDES permits.

##### *3.1.1.1 Individual VPDES Permits*

There is currently one facility with an active individual permit within the project area and this facility is expected to discharge the applicable pollutant of concern (bacteria). This facility is

characterized as minor municipal (discharge design flow less than 1.0 million gallons per day).

Table 3-1 outlines pertinent information about the individual permit and Figure 3-1 illustrates the location of the individual permit within the project area.

*Table 3-1. Applicable facilities with active VPDES individual permits that discharge in the project area*

Permit No	Facility Name	Maximum Design Flow (MGD)	Facility Type	Receiving Stream	TMDL Watershed
VA0023329	DOC – Caroline Correctional Unit 2	0.037	Municipal	UT to Herring Creek	Herring Creek

### *3.1.1.2 General VPDES Permits*

In Virginia, owners of domestic sewage treatment systems with design flows of less than or equal to 1,000 gallons per day on a monthly average basis register to be regulated under the terms of the VPDES domestic sewage ("single family home") general permit. There are currently no facilities with active general permits that are expected to discharge the applicable pollutant of concern (bacteria) within the project area. General permits that are not expected to discharge bacteria are listed below in Table 3-2 and illustrated in Figure 3-1.

*Table 3-2. Facilities with VPDES general permits that discharge in the project area but are not expected to discharge bacteria*

County	TMDL Watershed	Permit No	Facility Name	Facility Type	Receiving Stream
King and Queen	Mattaponi River, Tidal Segment	VAG840161	Essex Concrete-Aylett Sand and Gravel	Nonmetallic Mineral Mining	Mattaponi River
		VAR051929	Bennett Mineral Company	Storm Water Industrial	Mattaponi River, Walkerton Branch
		VAG840187	Bennett Mineral Company	Nonmetallic Mineral Mining	Mattaponi River
		VAG840242	Bennett Mineral Company	Nonmetallic Mineral Mining	Mattaponi River
	Dickeys Swamp	VAR052327	Branscome Inc.	Storm Water Industrial	Mattaponi River, Dickeys Swamp
Essex	XJG-Dickeys Swamp, UT	VAG110203	R R Beasley Incorporated	Concrete Products	Mattaponi River, Dickeys Swamp, UT

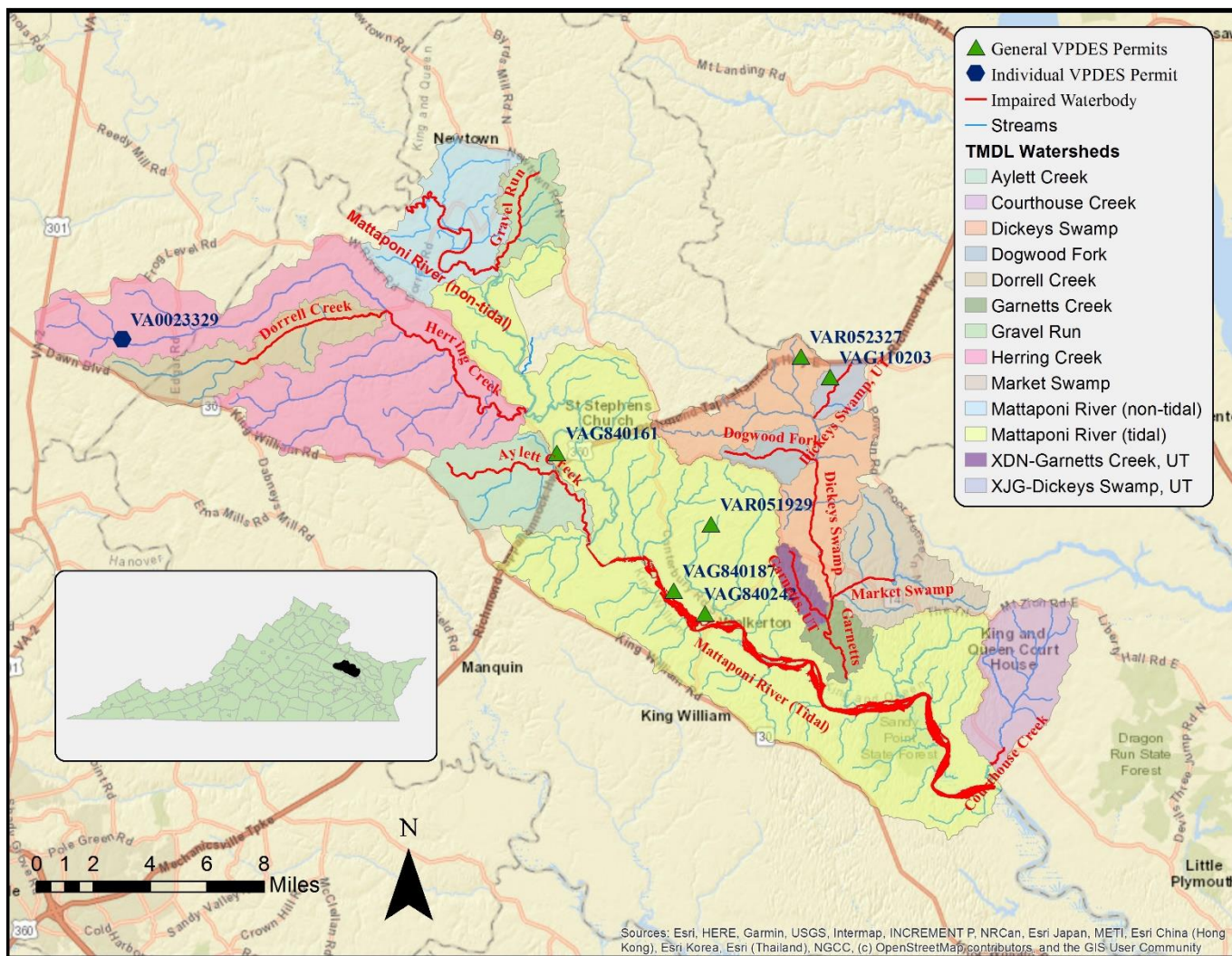


Figure 3-1. General and Individual VPDES permits in the project area

### 3.1.2 MS4 Permits

Discharges from municipal separate storm sewer systems (MS4s) are regulated under the Virginia Stormwater Management Act, the Virginia Stormwater Management Program (VSMP) Permit regulations, and the Clean Water Act as point source discharges. MS4 regulations were developed and implemented in two phases. Implementation of the first phase began in the early 1990s and required that operators of MS4s serving populations of greater than 100,000 people (per the 1990 decennial census) apply for and obtain a permit to discharge stormwater from their outfalls. The second phase of MS4 regulations became effective March 23, 2003, and required that operators of small MS4s in "urbanized areas" (as defined by the latest decennial census) obtain a permit to discharge stormwater from their outfalls. Areas included in MS4 permits may contribute bacteria from land-based sources (pet, human, and/or wildlife) that can be present in runoff.

There are no MS4s within the project area.

### 3.1.3 Biosolids

Biosolids were applied to fields within the TMDL project area between the years 2008 and 2019; the total amount applied was 14,391 dry tons (Table 3-3); however, biosolids were not considered as a potential pollutant source for this project. The application of biosolids is regulated through the Virginia Pollution Abatement (VPA) program (9VAC25-32), which prohibits point source discharges of pollutants to surface waters, including wetlands, except in the case of a storm event greater than the 25-year, 24-hour storm. The VPA regulations were developed to ensure that neither infiltration nor runoff have an effect on aquifers. The regulation (9VAC25-32-560) requires the implementation of agricultural best management practices (BMPs) to reduce nonpoint source pollution from farmland. This includes restrictions on application timing, application rate, slope, and, in particular, setback distances from sensitive environmental features designed to control and restrict the movement of biosolids after application.

*Table 3-3. Biosolids application in the project area*

Year	Dry Tons Applied
2008	1418.78
2009	149.54
2010	812.34
2011	2702.99
2012	691.22
2013	1472.51
2014	1083.59
2015	2936.13
2016	843.08
2017	746.04
2018	420.47
1/1/19-09/25/19	1114.38
<b>TOTAL</b>	<b>14391.07</b>

#### 3.1.4 Animal Feeding Operations

Animal Feeding Operations (AFOs) are regulated through the Virginia Pollutant Abatement (VPA) permit program (9VAC25-32); however, no AFOs are found within the project area. The Virginia Pollution Abatement (VPA) regulation (9VAC25-32-30.A.) prohibits point source discharges of pollutants to surface waters, including wetlands, except in the case of a storm event greater than the 25-year, 24-hour storm.

### 3.2 Nonpoint Sources

Nonpoint fecal coliform sources and production rates in the Mattaponi River study area were assessed using information from a variety of state and federal agencies, as well as public participation, project area reconnaissance and monitoring, published information, and professional judgment. Potential nonpoint sources of fecal coliform in the study area are described in Sections 3.2.1 through 3.2.4.

#### 3.2.1 Septic Systems and Straight Pipes and Pit Privies

The number of households and the number of people per household were determined based on the 2010 U.S Census data (Census Bureau, 2010). Population and housing numbers are described

in Table 3-4, Table 3-5, and Table 3-6. The number of houses using various types of sewage disposal were obtained from the 1990 U.S. Census data and are listed in Table 3-7. The Census data provide estimates of housing units which discharge to public sanitary sewer, septic tanks, cesspools, or by ‘other means’ (Census Bureau, 1990). Ten percent of the houses in the ‘other means’ category (including straight pipes and pit privies connected to surface water) are assumed to discharge sewage directly into streams without treatment or die-off. The remaining 90% of ‘other means’ are pit privies that are not connected to surface waters. (VADEQ, 2014)

Typical septic systems consist of a septic tank, distribution box, and a drainage field. Waste from the household flows first to the septic tank, where solids settle out and are periodically removed by a septic tank pump-out. The liquid portion of the waste (effluent) flows to the distribution box, where it is distributed among several buried, perforated pipes that comprise the drainage field. Once in the soil, the effluent flows downward to groundwater, laterally to surface water, and/or upward to the soil surface. Removal of fecal bacteria is accomplished primarily by die-off during the time between introduction to the septic system and eventual introduction to naturally occurring waters. Properly designed, installed, and functioning septic systems contribute virtually no fecal bacteria to surface waters. In accordance with the Chesapeake Bay Preservation Act of 1988, jurisdictions within Tidewater Virginia require that all septic systems be pumped out at least once every five years.

A septic failure occurs when a drain field has inadequate drainage or a “break,” such that effluent flows directly to the soil surface, bypassing travel through the soil profile. In this situation, the effluent is either available to be washed into waterways during runoff events or is directly deposited in-stream due to proximity. Assuming an average Mean Time Before Failure (MTBF) or service life of a septic system to be 30 years, in any given year  $1/30$  of all septic systems are assumed to fail; therefore, the average annual failure rate of septic systems is 3.3%. These estimates of straight pipes, pit privies, and failing septic systems are included in Table 3-8.

Bacteria discharged from straight pipes enter the stream directly, without treatment or die-off. As stated earlier, the ‘other means’ category in the Census data (Census Bureau, 1990) included the houses that dispose of sewage other than by public sanitary sewer or a private septic system. These houses were assumed to be disposing of sewage via straight pipes or pit privies. Ninety

percent of the houses in the ‘other means’ category were assumed to dispose of sewage via pit privies and the other 10% were assumed to dispose of via straight pipes (VADEQ, 2014).

*Table 3-4. Population for each county in the project area*

Statistic	Caroline County	Essex County	King and Queen County	King William County
Population, 2010	814	4	1273	5049
Population, 2017 estimate <sup>1</sup>	868	4	1284	5294
Population, percent change, April 1, 2010 to July 1, 2017	6.7%	1.2%	0.8%	4.9%

<sup>1</sup>Estimated based on the county-scale population growth found in the 2010 Census.

*Table 3-5. Number of housing units in each county in the project area*

Statistic	Caroline County	Essex County	King and Queen County	King William County
Housing Unit, 2010	334	2	626	2066
Housing Unit, 2017 estimate	349	2	641	2200
Housing Unit, percent change, April 1, 2010 to July 1, 2017	4.5%	3.3%	2.5%	6.5%

*Table 3-6. Estimated population and number of housing unit within the project area*

TMDL Watershed	Population	Number of Houses
Aylett Creek	525	218
Courthouse Creek	120	60
Dickeys Swamp	207	104
Dogwood Fork	30	15
Dorrell Creek	596	246
Garnetts Creek	33	16
Gravel Run	55	27
Herring Creek	2569	1058
Market Swamp	120	60
Mattaponi River, Tidal Segment	2763	1198
Mattaponi River	384	166
XJG-Dickeys Swamp, UT	26	13
XDN-Garnetts Creek, UT	23	12

*Table 3-7. Number of houses that use public sewers, septic systems, or other means of sewage disposal (based on 1990 Census data) in the project area*

TMDL Watershed	Public Sewer	Septic System	Other Means
Aylett Creek	60	147	11
Courthouse Creek	0	55	4
Dickeys Swamp	1	96	7
Dogwood Fork	0	14	1
Dorrell Creek	62	172	13
Garnetts Creek	0	15	1
Gravel Run	0	25	2
Herring Creek	243	755	60
Market Swamp	0	56	4
Mattaponi River	35	122	9
Mattaponi River, Tidal Segment	251	883	64
XDN-Garnetts Creek, UT	0	11	1
XJG-Dickeys Swamp, UT	0	12	1

*Table 3-8. Estimated number of straight pipes, pit privies, and failing septic systems in the project area*

TMDL Watershed	Number of Straight Pipes	Number of Pit Privies	Number of Failing Septic Systems
Aylett Creek	1	10	4
Courthouse Creek	0	4	2
Dickeys Swamp	1	6	3
Dogwood Fork	0	1	0
Dorrell Creek	1	12	5
Garnetts Creek	0	1	0
Gravel Run	2	0	1
Herring Creek	6	54	23
Market Swamp	0	4	2
Mattaponi River	1	8	4
Mattaponi River, Tidal Segment	6	58	26
XDN-Garnetts Creek, UT	0	1	0
XJG-Dickeys Swamp, UT	0	1	0

### 3.2.2 Pets

Dogs are the predominant pet source of bacteria in the project area; runoff carries bacteria from dog waste deposited on land to water during rainfall events. The bacteria load from cats is negligible compared to dogs. The average numbers of dogs per household were obtained from the American Veterinary Medical Association (AVMA, 2012) and/or the Humane Society of the United States biennial American Pet Products Associated National Pet Owners Survey for the United States (HSUS, 2012) and were used in conjunction with the number of households in the project area to estimate the number of dogs. The AVMA formula for determining the number of household dogs based on national data is the number of households multiplied by 0.58. The estimated number of dogs in each TMDL watershed is presented in Table 3-9 below.

*Table 3-9. Estimated dog populations in project area*

TMDL Watershed	Households (2017 Estimate)	Number of Dogs
Aylett Creek	218	139
Courthouse Creek	60	38
Dickeys Swamp	104	66
Dogwood Fork	15	10
Dorrell Creek	246	157
Garnetts Creek	16	10
Gravel Run	27	17
Herring Creek	1058	675
Market Swamp	60	38
Mattaponi River	166	106
Mattaponi River, Tidal Segment	1198	764
XDN-Garnetts Creek, UT	12	8
XJG-Dickeys Swamp, UT	13	8

### 3.2.3 Livestock

Bacteria from animal waste may enter surface water either directly through excretion into a waterway at access points or indirectly via runoff. The average bacteria load generated by each animal depends on the animal type and management practices employed by the property owner (such as livestock stream exclusions). United States Department of Agriculture (USDA) Census of Agriculture data were used to estimate livestock populations within the project area (USDA,

2012). The estimates were revised based on stakeholder input. The estimated livestock populations are summarized in Table 3-10.

*Table 3-10. Estimated livestock populations in the project area*

TMDL Watershed	Beef Cows	Milk Cows	Goats	Hogs and Pigs	Horses and Ponies	Sheep and Lambs	Chickens
Aylett Creek	7	2	1	11	14	0	24
Courthouse Creek	53	0	21	5	69	10	147
Dickeys Swamp	3	0	1	1	14	1	9
Dogwood Fork	2	0	0	0	6	0	3
Dorrell Creek	2	2	0	7	7	0	11
Garnetts Creek	6	0	2	2	10	1	17
Gravel Run	3	1	1	6	6	0	11
Herring Creek	25	4	10	23	61	3	75
Market Swamp	3	1	1	4	9	0	9
Mattaponi River	6	2	2	4	21	2	15
Mattaponi River, Tidal Segment	61	7	19	28	120	9	163
XDN-Garnetts Creek, UT	2	0	1	0	6	1	3
XJG-Dickeys Swamp, UT	0	0	0	0	1	0	1

Average daily fecal coliform bacteria production rates are presented in Table 3-11. Beef and dairy cows have the highest average bacteria production rates, followed by other cows and hogs.

*Table 3-11. Average daily fecal coliform bacteria production rates for each livestock type*

Livestock Type	Daily Fecal Coliform Production (cfu/day)	Reference
Other Dairy Cow (including heifers)	1.16E+10	Virginia Tech, 2000
Beef Cows	3.30E+10	Virginia Tech, 2000
Dairy Cows	2.52E+10	Virginia Tech, 2000
Hogs	1.08E+10	ASAE, 1998
Sheep	2.70E+10	Virginia Tech, 2000
Horses	4.20E+08	Virginia Tech, 2000
Chickens	1.36E+08	ASAE, 1998

Beef cattle spend varying amounts of time in streams and pastures, depending on the time of year. Accordingly, the proportion of fecal coliform deposited in any given land area varies throughout the year. Stream access for all beef cattle farms was estimated based on project area visits and pasture proximity to the stream.

The following assumptions and procedures were used to estimate the distribution of cattle (and thus, fecal coliform produced by cattle) among different land use types and in streams:

- a) Cattle with stream access will spend varying amounts of time in the stream during different seasons (Table 3-12 and Table 3-13). Cattle spend more time in the stream during the three summer months to protect their hooves from hornflies, among other reasons.
- b) Thirty percent of cattle in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the feces is deposited on pastures.

*Table 3-12. Average daily schedule for beef cattle by month*

Month	Pasture (hours)	Stream (hours)
January	23.50	0.50
February	23.50	0.50
March	23.25	0.75
April	23.00	1.00
May	23.00	1.00
June	22.75	1.25
July	22.75	1.25
August	22.75	1.25
September	23.00	1.00
October	23.25	0.75
November	23.25	0.75
December	23.50	0.50

*Table 3-13. Average daily schedule for dairy cattle by month*

Month	Pasture (hours)	Stream (hours)
January	7.70	0.25
February	7.70	0.25

Month	Pasture (hours)	Stream (hours)
March	8.60	0.50
April	10.10	0.75
May	10.80	0.75
June	11.30	1.00
July	11.80	1.00
August	11.80	1.00
September	11.80	0.75
October	11.50	0.50
November	10.80	0.50
December	9.40	0.25

### 3.2.4 Wildlife

The predominant wildlife species in the project area were determined through consultation with wildlife biologists from the Virginia Department of Wildlife Resources (VDWR), and project stakeholders. The wildlife populations were estimated by combining typical wildlife densities with available stream habitat, which were generated based on GIS data of land use and streams (Table 3-14 and Table 3-15).

*Table 3-14. Wildlife habitats and population densities in the project area*

Species	Suitable Habitat	Typical Population Density
Deer	Whole project area except open water, high intensity development	0.0344 animals/acre
Raccoon	Within 600 feet of streams and ponds	0.07 animals/acre
Muskrat	Within 66 feet of streams and ponds	2.75 animals/acre
Beaver	Within 66 feet of streams and ponds	4.8 animals/mile of stream
Goose	Whole project area	0.02 animals/acre
Wild Turkey	Whole project area except open water, high intensity development	0.0344 animals/acre
Ducks	Urban, residential, grassland, pasture, wetland, scrub/shrub, barren within 300 feet of streams and ponds	0.078 animals/acre

*Table 3-15. Estimated wildlife populations in the project area*

Watershed	Deer	Raccoon	Muskrat	Beaver	Wild Turkey	Duck	Goose
Aylett Creek	184	185	800	88	53	38	109
Courthouse Creek	197	231	994	109	59	39	119
Dickeys Swamp	336	469	2028	221	99	75	200
Dogwood Fork	49	65	283	31	14	8	30
Dorrell Creek	198	213	921	101	58	40	118
Garnetts Creek	51	41	176	20	16	15	32
Gravel Run	92	56	244	27	27	3	54
Herring Creek	807	882	3811	418	234	174	486
Market Swamp	198	251	1081	118	58	39	118
Mattaponi River	232	362	1567	171	67	81	142
Mattaponi River, Tidal Segment	1688	2604	11259	1227	490	581	1039
XDN-Garnetts Creek, UT	39	44	191	21	12	7	24
XJG-Dickeys Swamp, UT	42	51	219	24	12	7	25

## 4 MODELING APPROACH

---

A key component in developing a TMDL is establishing the relationship between pollutant loadings (both point and nonpoint) and in-stream water quality conditions. Once this relationship is developed, management options for reducing pollutant loadings to streams can be assessed. In developing a TMDL, it is critical to understand the processes that affect the fate and transport of the pollutants and cause the impairment of the water body of concern. Pollutant transport to water bodies is evaluated using a variety of tools, including water quality monitoring, GIS, and computer simulation models. This project includes both non-tidal and tidal waterbodies.

Hydrologic Simulation Program FORTRAN (HSPF) is used to model bacterial loadings from all sub-watersheds (tidal and non-tidal) except those adjacent to the Mattaponi River, non-tidal hydrology, and non-tidal water quality. It is also used for TMDL allocations in non-tidal waterbodies. The sub-watersheds adjacent to the Mattaponi River were simulated by the Loading Simulation Program in C++ (LSPC) watershed model, which has identical model components to HSPF. The results from the HSPF and LSPC models provide inputs to the Environmental Fluid Dynamics Computer Code (EFDC) model, which is used to model hydrology and water quality in the tidal waterbodies.

### 4.1 Modeling Goals, Considerations and Assumptions

The primary goals of the model development are to provide a tool to quantitatively determine bacteria loads and reduction targets and generate allocation scenarios. The model should take into account the following considerations:

- Ensure proper applications of topographic, hydrographic, landscape, climate, and water quality variables in a watershed system over a specific period of time
- Include point and nonpoint pollution sources of bacteria as comprehensively as possible, quantify their contributions and seasonal variations
- Utilize meteorological, flow, and water quality data to precisely simulate the time varying nature of environmental conditions
- Calibrate by comparing simulated data with recorded values under various climatic and watershed conditions

- Allow for direct comparison between modeled in-stream conditions and water quality standards

The remainder of this section and section 5 discuss the HSPF model development and the TMDL allocations in non-tidal waterbodies and section 6 provides EFDC model development and TMDL allocations for tidal waterbodies.

#### 4.2 Modeling Software - HSPF (EFDC discussed in Section 6)

The Hydrologic Simulation Program FORTRAN (HSPF), one of the few of models that are able to fulfill the modeling objectives mentioned above, has become the preferred model for the development of bacteria TMDLs in Virginia. HSPF was used for the non-tidal impairments in the project area. The model used for the tidal impairments is discussed in Section 6. HSPF is a continuous simulation model that can handle temporal and spatial variability of water quality constituents from various sources, including land uses. Users have exceptional flexibility in defining temporal and spatial variability of watershed characteristics, hydrologic and water quality modeling capabilities, accurate representation of individual point sources, climatic data handling capabilities, the ability to track water and the fate and transport of pollutants from land based sources, and the ability to calibrate and validate the model from HSPF. A number of additional software packages were used to complete the modeling task in an organized and expeditious way.

The HSPF model accepts input data as numbers and specific texts as instructions. A GIS-based data analysis and modeling tool was used to derive the input data and their relationships with other data entered into the model. The ArcMap<sup>TM</sup> GIS software package from Esri was utilized along with a number of custom tools to perform the pre-processing tasks and extract the necessary data. Supporting software, such as WDMUtil and Annie were used to prepare meteorological time-series input and create binary WDM files. HSPF can efficiently read and write the time-series data that are stored in WDM files. These public domain software packages are readily available from the EPA and USGS. HSPEXP, an expert system for hydrologic calibration using HSPF, was used to refine model calibration and generate calibration and validation statistics.

In watershed modeling, large watersheds are segmented into a number of smaller subwatersheds comprised of major tributaries, land segments/land uses, and point source discharges. All spatial data are organized by these subwatersheds and similar sources are grouped in the model input. Once a preliminary model with physical and meteorological input is created, the model is sequentially calibrated for flow and bacteria. HSPF produces nonpoint source runoff and loads from land-based sources and directs those to adjacent stream segments. Flow in the stream segments is routed downstream with water quality constituents. Appropriate land-based and in-stream processes are chosen and parameterized through model calibration and sensitivity analyses. The modeled stream flow and pollutant concentrations are judged against observed data from flow gages and water quality monitoring stations for model calibration and validation.

Appendix C includes additional detail describing the results and parameters of the model and Appendix D includes a model sensitivity analysis.

#### 4.2.1 Boundary Conditions

Mattaponi River (tidal segment), Garnetts Creek, Dickey's Swamp, and Herring Creek TMDL watersheds are located downstream of one or more impaired segments; all other TMDL watersheds are located in headwaters or downstream of unimpaired stream reaches. The outlets of headwater TMDL watersheds defined the upstream boundaries of these lower impaired reaches. TMDLs are developed starting with the upstream reaches and sequentially moving to downstream reaches.

#### 4.2.2 Simulation Period

Available USGS flow gage data, weather data, and water quality data were reviewed to select suitable modeling periods for hydrologic and water quality calibration and validation of the model. The downstream USGS flow gages in the project area are directly affected by the flow at upstream gages and, therefore, the flow data from different gages were not deemed independent. The flow time series data from a single flow gage had to be divided into two periods for hydrologic calibration and validation. Since representative precipitation data for the TMDL watersheds were available until December 31, 2017, the three-year period between January 1, 2015 and December 31, 2017 was selected for hydrologic calibration and the three-year period between January 1, 2012 and December 31, 2014 was selected for model hydrologic validation.

The determination of water quality calibration and validation periods for the model depends on the availability of DEQ's monitoring data and the period of available data. Water quality data from at least one DEQ monitoring station were available in each TMDL watershed (Table 4-1). Model calibration and validation utilized the DEQ monitoring stations that were used for listing impairments in the Final 2016 and 2018 305(b)/303(d) Water Quality Assessment Integrated Reports (VADEQ, 2018a). The data from the period January 1, 2010 to December 31, 2017 were employed for water quality calibration and validation.

*Table 4-1. DEQ monitoring stations used in the calibration and validation of the HSPF model*

TMDL Watershed	Model Segment	Water Quality Monitoring Station	Calibration, Number of Samples	Calibration Period	Validation, Number of Samples	Validation Period
Aylett Creek	Reach 286	8-AYL002.27	12	1/1/2017 – 12/31/2017	n/a	n/a
Courthouse Creek	Reach 203	8-CTH001.96	12	1/1/2014 – 12/31/2014	n/a	n/a
Dickeys Swamp	Reach 223	8-DKW000.12	23	1/1/2015 – 12/31/2017	12	1/1/2011 – 12/31/2011
Dogwood Fork	Reach 232	8-DWD000.77	12	1/1/2016 – 12/31/2016	12	1/1/2011 – 12/31/2011
Garnetts Creek	Reach 215	8-GNT001.54	12	1/1/2017 – 12/31/2017	11	1/1/2011 – 12/31/2011
Herring Creek-DS	Reach 263	8-HER000.33	24	1/1/2014 – 12/31/2016	n/a	n/a
Market Swamp	Reach 218	8-MKT001.04	12	1/1/2017 – 12/31/2017	12	1/1/2011 – 12/31/2011
Mattaponi River (non-tidal)	Reach 10	8-MPN083.62	92	1/1/2013 – 12/31/2017	n/a	n/a
XDN-Garnetts Creek, UT	Reach 235	8-XDN000.12	9	1/1/2017 – 12/31/2017	11	1/1/2011 – 12/31/2011
XJG-Dickeys Swamp, UT	Reach 227	8-XJG000.08	12	1/1/2011 – 12/31/2011	n/a	n/a
Gravel Run	Reach 294	8-GVL000.56	12	1/1/2016 – 12/31/2016	n/a	n/a
Dorrell Creek	Reach 272	8-DRL000.85	12	1/1/2016 – 12/31/2016	n/a	n/a

### 4.3 Development of the Project Area Model

Watershed specific HSPF model development can be broken down into three steps:

- Initial model setup
- Hydrologic calibration and validation

- Water quality calibration and validation

The initial model setup involves planning and processing of input data that are described earlier in Section 2 Watershed Characterization. The model parameters that may vary within reasonable ranges, but cannot be readily and accurately obtained from field observations, are established through the calibration process. Hydrologic calibration establishes the values of site-specific parameters that govern the hydrologic processes. Water quality calibration helps to estimate the values of rates, constants, and kinetic coefficients involving bacteria fate and transport processes. These steps are further elaborated in the next sections.

#### 4.3.1 Initial Model Setup

##### *4.3.1.1 4.3.1.1 Watershed Delineation and Data Development*

Watershed delineation is the process of segmenting a drainage area into smaller units (subwatersheds). The goal is to improve the representation of the hydrologic and water quality characteristics of the drainage area in the model. Though subwatersheds cannot be direct inputs in the HSPF model, subwatershed boundaries define the physical connectivity of land uses to stream reaches and reservoirs and the acreage of each land use type draining to a reach. Overlaying the subwatershed boundary layer on the GIS land use coverage map helps determine the acreage of various land uses in each subwatershed.

Watershed delineation was performed using an ArcGIS based watershed delineation tool that utilizes the Digital Elevation Model (DEM) data representing basin topography and DEQ's hydrographic data describing natural stream centerlines. The locations of the significant changes in the stream or subwatershed characteristics (i.e. area, width, slope, etc.), stream confluences, dams, flow gages, and water quality monitoring stations were considered in specifying the outlets of individual subwatersheds. As a starting point, the 6th Order Hydrologic Unit Code (HUC) areas were provided as the outermost boundaries. The process segmented the project area into 98 modeling subwatersheds that include areas outside the TMDL watersheds; watershed delineation was completed for the entire project area to facilitate automatically performing the task for all impaired watersheds in a single operation. Table 4-2 shows the size distributions of

98 subwatersheds delineated in the Project Area and Figure 4-1 shows a map of all the delineated subwatersheds.

*Table 4-2. TMDL Modeling Area Segments in Impaired Watersheds*

TMDL Watershed	Model Segment	Drainage Area (acres)	VAHU6	Total Area (acres)
Aylett Creek	284	12.3	YO57	5468.5
	285	1076.7	YO57	
	286	1907.9	YO57	
	287	1211.8	YO57	
	288	1259.8	YO57	
Courthouse Creek	203	581.3	YO59	5887.4
	204	1090.1	YO59	
	205	1341.0	YO59	
	206	1893.3	YO59	
	207	981.7	YO59	
Dickeys Swamp	222	14.2	YO58	10068.7
	223	408.2	YO58	
	224	1799.4	YO58	
	225	1361.9	YO58	
	226	1852.5	YO58	
	229	2220.1	YO58	
	230	2412.3	YO58	
Dogwood Fork	231	386.4	YO58	1454.4
	232	529.4	YO58	
	233	538.6	YO58	
Garnetts Creek	214	76.0	YO58	1613.3
	215	1366.4	YO58	
	216	170.9	YO58	
Herring Creek	263	1070.7	YO56	24319.6
	264	748.5	YO56	
	265	908.9	YO56	
	266	173.5	YO56	
	267	2435.8	YO56	
	268	2533.3	YO56	
	269	1870.9	YO56	
	270	2627.6	YO56	
	271	2873.6	YO56	
	276	1626.1	YO56	

TMDL Watershed	Model Segment	Drainage Area (acres)	VAHU6	Total Area (acres)
	277	732.9	YO56	
	278	792.9	YO56	
	279	1072.7	YO56	
	280	490.4	YO56	
	281	1238.0	YO56	
	282	951.9	YO56	
	283	2171.9	YO56	
Dorrell Creek	272	1503.1	YO56	5892.5
	273	1668.4	YO56	
	274	1394.2	YO56	
	275	1326.8	YO56	
Market Swamp	217	1183.1	YO58	5910.1
	218	1708.2	YO58	
	219	13.2	YO58	
	220	1602.0	YO58	
	221	1403.6	YO58	
Mattaponi River	9	3958.7	YO55	7125.7
	10	3167.0	YO55	
XDN-Garnetts Creek, UT	234	176.1	YO58	1144.9
	235	386.4	YO58	
	236	582.3	YO58	
XJG-Dickeys Swamp, UT	227	651.7	YO58	1244.4
	228	592.7	YO58	
Gravel Run	294	2693.1	YO55	2693.1
Mattaponi River Tidal Segment	1	516.5	YO55	51884.0
	8	4244.0	YO55	
	201	35.3	YO59	
	202	360.7	YO59	
	208	3190.5	YO59	
	209	4430.0	YO59	
	210	1896.1	YO59	
	211	1311.9	YO59	
	212	2179.0	YO59/YO57	
	213	436.6	YO58	
	237	1957.6	YO57	
	238	1567.9	YO57	

TMDL Watershed	Model Segment	Drainage Area (acres)	VAHU6	Total Area (acres)
	239	251.4	YO57	
	240	1533.5	YO57	
	241	240.6	YO57	
	242	1182.2	YO57	
	243	1111.7	YO57	
	244	943.3	YO57	
	245	1097.6	YO57	
	246	1182.3	YO57	
	247	146.2	YO57	
	248	1274.1	YO57	
	249	1203.5	YO57	
	250	2089.8	YO57	
	251	715.5	YO57	
	252	1273.8	YO57	
	253	3.2	YO57	
	254	877.5	YO57	
	255	1031.1	YO57	
	256	1286.1	YO57	
	257	1723.9	YO57	
	258	1573.3	YO57	
	259	374.7	YO57	
	260	1830.2	YO57	
	261	1738.8	YO57	
	262	306.6	YO57	
	289	1247.8	YO57	
	290	1422.8	YO57	
	291	130.1	YO57	
	292	1194.7	YO57	
	293	771.6	YO57	

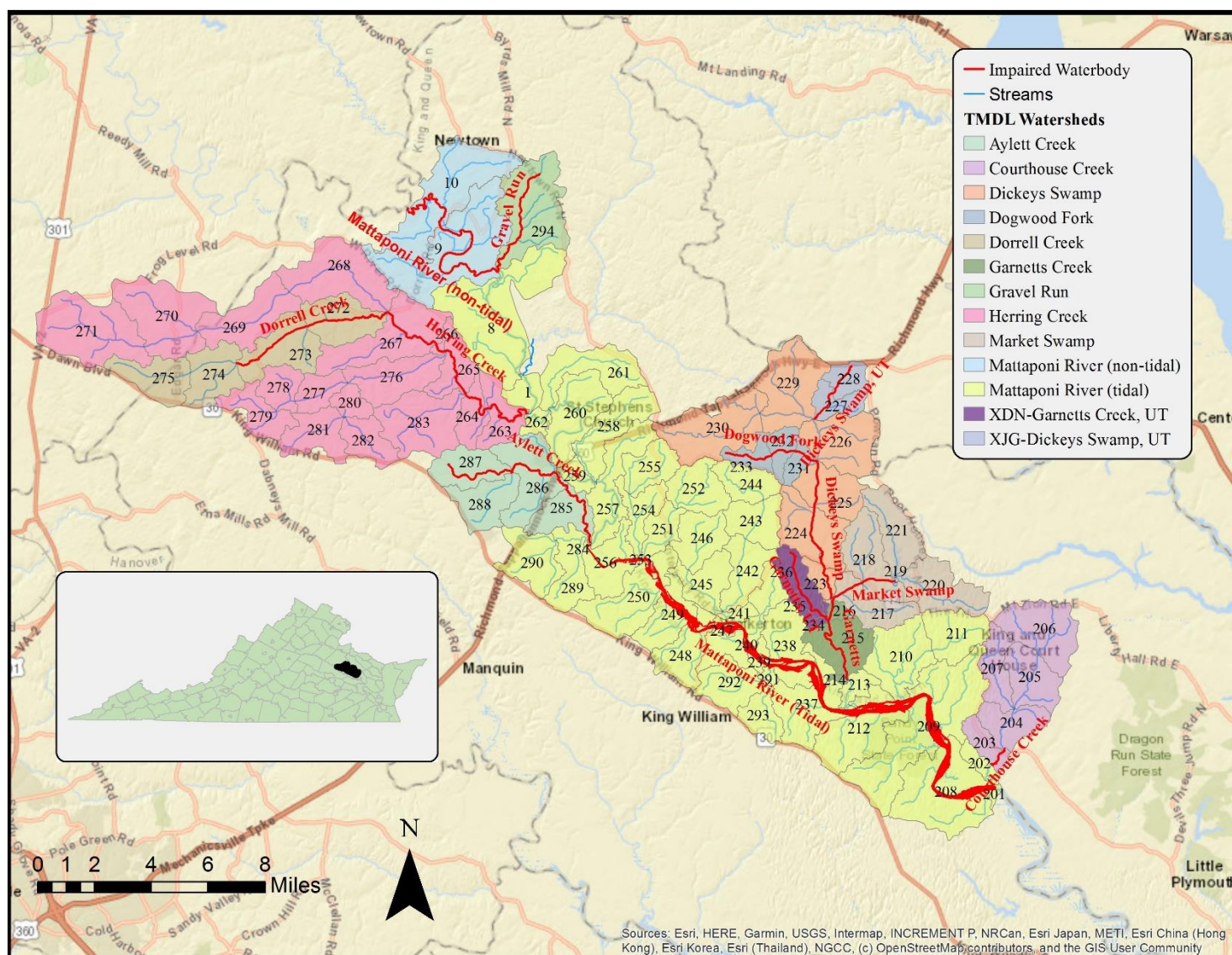


Figure 4-1. TMDL Modeling Area Segments

#### 4.3.1.2 4.3.1.2 Land Use Reclassification

Each land use denoted in the HSPF model must be accurately parameterized for hydrology and water quality simulations. However, this task becomes overwhelmingly complex and inefficient with increasing number of land use classes as substantially more data are needed to set up and calibrate the model. If only land uses that cover large areas of the drainage area and act as the most significant sources of runoff and bacteria loads are included in the model, the approach taken is much simpler. Accordingly, the original 16 NLCD land use classes are regrouped, as shown in Table 4-3, to reduce the number of land uses that can be modeled. Distinction between hay land and pastureland is made according to the 2012 National Agricultural Statistics Service (NASS) Crop Data Layer in order to address the additional bacteria accumulation from cattle-waste deposited on pastureland during grazing.

*Table 4-3. A reclassification scheme to convert 2011 NLCD land use classes to fewer classes for modeling*

NLCD Land Use Class	Reclassified Land Use
Barren Land (Rock/Sand/Clay)	Barren Land (Rock/Sand/Clay)
Cultivated Crops	Crop
Developed, Open Space	Developed Urban Area
Deciduous Forest	Forest
Evergreen Forest	Forest
Mixed Forest	Forest
Shrub/Scrub	Forest
Hay	Hay
Developed, High Intensity	High Density Residential
Developed, Low Intensity	Low Density Residential
Developed, Medium Intensity	Medium Density Residential
Grassland/Herbaceous	Pasture
Pasture	Pasture
Open Water	Water/Wetland
Woody Wetlands	Water/Wetland
Emergent Herbaceous Wetlands	Water/Wetland

#### 4.3.1.3 Hydrographic Data and F-Table Generation

At the time of the delineation of the subwatersheds, the hydrographic data showing the stream network and bearing stream characteristics were obtained from DEQ's GIS hydrography data layer. HSPF model input preparation and TMDL development were facilitated with these stream data.

The HSPF model entails stream reach connectivity, length, slope, and a table denoting the depth-volume-discharge correlation for each reach. These tables allow for the simulation of hydraulics through the reach and reservoir network and are called Function-Tables or F-Tables. An F-Table was populated for each modeled reach by obtaining elevation data from the DEM along the hand-drawn cross-section cut lines and using the Manning's equation; the F-tables were added to the model input file.

#### 4.3.2 Watershed Data Management (WDM) Preparation

Watershed Data Management (WDM) files store historical time series input data (such as rainfall and evapotranspiration), model boundary condition and calibration data (e.g. stream flow measurements), point source discharge data, and outputs. Data stored in a WDM file are easily linked to model inputs, managed, modified, and exported to any tabular forms. Details of climatic data available from local stations are elaborated in Section 2.2. The final selection of the rainfall data was carried out during the model setup and calibration processes. After carefully reviewing the gage locations and the extent, time interval, and the quality of the data, it was determined that none of the precipitation stations near the project area proved sufficient for long-term hydrologic modeling and TMDL development. Precipitation data collected from the Tropical Rainfall Measuring Mission (TRMM) were analyzed and evaluated as an alternate measure. TRMM is a joint mission between the National Aeronautics and Space Administration (NASA) and the Japan Aerospace Exploration Agency (JAXA) devised to monitor and study tropical rainfall. TRMM provided precipitation data from 1998 through 2018 at a three hour interval. The data were desegregated into hourly intervals.

#### 4.3.3 Hydrologic Calibration

The calibration process ensures the accuracy of the model output for a given set of conditions by comparing the model results with observed data. The parameters that control different flow

components, e.g. surface runoff, interflow and base flow, are adjusted during the calibration to make the model results better agree with the observed values.

The daily average flow data observed from the USGS daily flow gage (USGS gage ID 01674500) located near Beulahville, VA, along the Mattaponi River were utilized to calibrate and validate the HSPF model. There are a number of reservoirs in the project area, but discharge data were not readily available for this modeling task. The drainage area of the Mattaponi River gage is 603 square miles.

Stream flow data from the years 2012 through 2017 were split into two periods: one for model calibration and the other for model validation. The hydrologic calibration of the model was performed over a three-year period from January 1, 2015 through December 31, 2017 and the model validation was performed over another three-year period from January 1, 2012 through December 31, 2014.

The simulated and observed statistics for the following selected hydrologic components were compared to execute the hydrologic calibration of the model:

- Total runoff, in inches
- Total of highest 10% flows, in inches
- Total of lowest 50% flows, in inches
- Total storm volume, in inches
- Base-flow recession rate
- Summer flow volume, in inches
- Winter flow volume, in inches
- Summer storm volume, in inches

To get a comprehensive calibrated and validated model, the following specific numeric targets were verified:

- Error in 50% lowest flows    +/-10%
- Error in 10% highest flows    +/-15%
- Error in low flow recession    +/-10%
- Summer storm volume error    +/-15%

- Error in total volume                      +/-10%

#### 4.3.3.1 Hydrologic Calibration Results

The HSPEXP software was utilized to calibrate the hydrologic model. Summary statistics were estimated after executing each iteration of the model and comparing the model results with the observed values. The built-in rules extracted from the experience of expert modelers are used as a basis for fine-tuning the calibration parameters, which are recorded in the HSPEXP user manual (Lumb and Kittle, 1993).

Utilizing the suggested criteria (referred to in the preceding section) as target values for an acceptable hydrologic calibration, the hydrologic model was calibrated for January 1, 2015 through December 31, 2017 at the USGS flow station 01674500 (Mattaponi River near Beulahville, VA). Table 4-4 below shows the model calibration results comparing the simulated and observed values. Table 4-5 presents an error statistics summary for five flow conditions. Figure 4-2 shows the plots of the model results and the observed daily average flow at USGS Station 01674500.

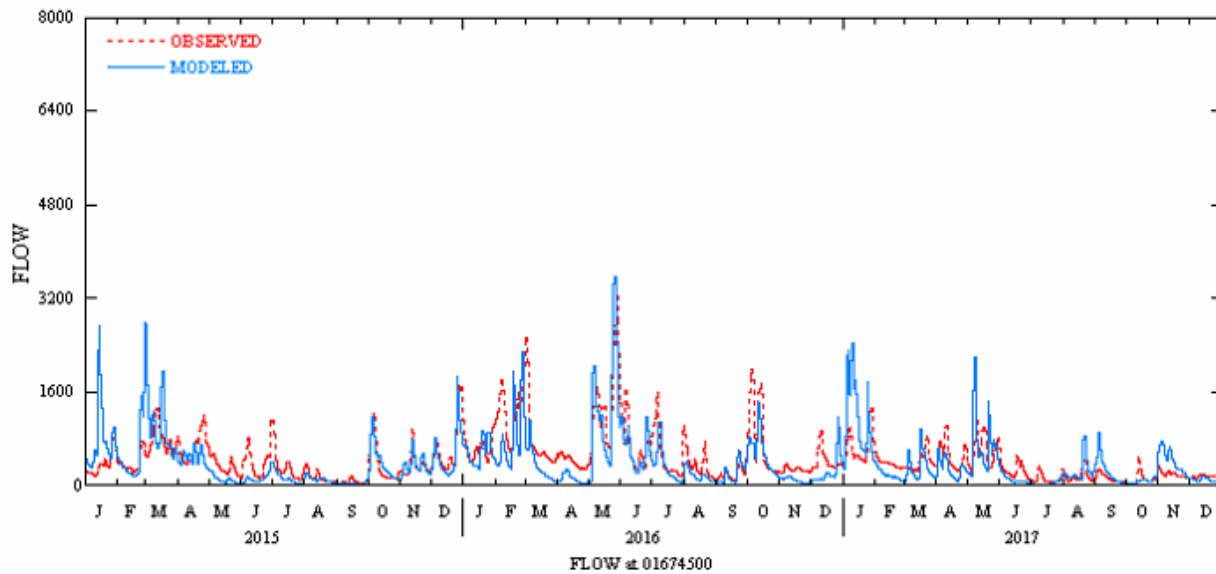
*Table 4-4. The hydrologic model calibration summary at USGS Station 01674500*

Description	Modeled Value	Observed Value
Total runoff, in inches	26.569	29.308
Total of highest 10% flows, in inches	10.597	11.314
Total of lowest 50% flows, in inches	18.195	17.979
Total storm volume, in inches	5.154	4.887
Average of storm peaks, in cfs	2029.3	2140
Baseflow recession rate	0.917	0.918
Summer flow volume, in inches	3.513	3.205
Winter flow volume, in inches	10.368	10.691
Summer storm volume, in inches	0.102	0.112

*Table 4-5. The hydrologic calibration results -- error statistics at USGS Station 01674500*

Description	Value	Criteria
Error in total volume	9.340	10.00
Error in low flow recession	0.005	0.01
Error in 50% lowest flows	8.215	10.00

Description	Value	Criteria
Error in 10% highest flows	6.773	15.00
Error in storm peaks	6.987	15.00



*Figure 4-2. The project area HSPF model hydrologic calibration results at USGS Station 01674500*

#### 4.3.3.2 Hydrologic Validation

Model validation confirms the credibility of the hydrologic model developed through model calibration. The validation process compares the model output to an observed dataset that is independent of the data used in the calibration process. The model's prediction accuracy is exhibited through the outcome of the process.

The project area HSPF model hydrology validation was carried out over a three-year period from January 1, 2012 through December 31, 2014. The validation results summary and statistics have been recorded in Table 4-6 and Table 4-7 below, which are analogous to the model calibration results. The final model output and observed flow within the total validation period are illustrated in Figure 4-3.

*Table 4-6. The project area HSPF model hydrologic validation summary at USGS Station 01674500*

Description	Modeled Value	Observed Value
Total runoff, in inches	27.265	30.155
Total of highest 10% flows, in inches	10.413	9.808
Total of lowest 50% flows, in inches	4.446	5.914
Total storm volume, in inches	2.216	2.398
Average of storm peaks, in cfs	827.57	863.38
Base flow recession rate	0.915	0.917
Summer flow volume, in inches	4.524	5.367
Winter flow volume, in inches	9.699	9.217
Summer storm volume, in inches	0.244	0.211

*Table 4-7. The project area HSPF model hydrologic validation result error statistics at USGS Station 01674500*

Description	Value	Criteria
Error in total volume	9.584	10.00
Error in low flow recession	0.005	0.01
Error in 50% lowest flows	1.744	10.00
Error in 10% highest flows	6.364	15.00
Error in storm peaks	4.327	15.00

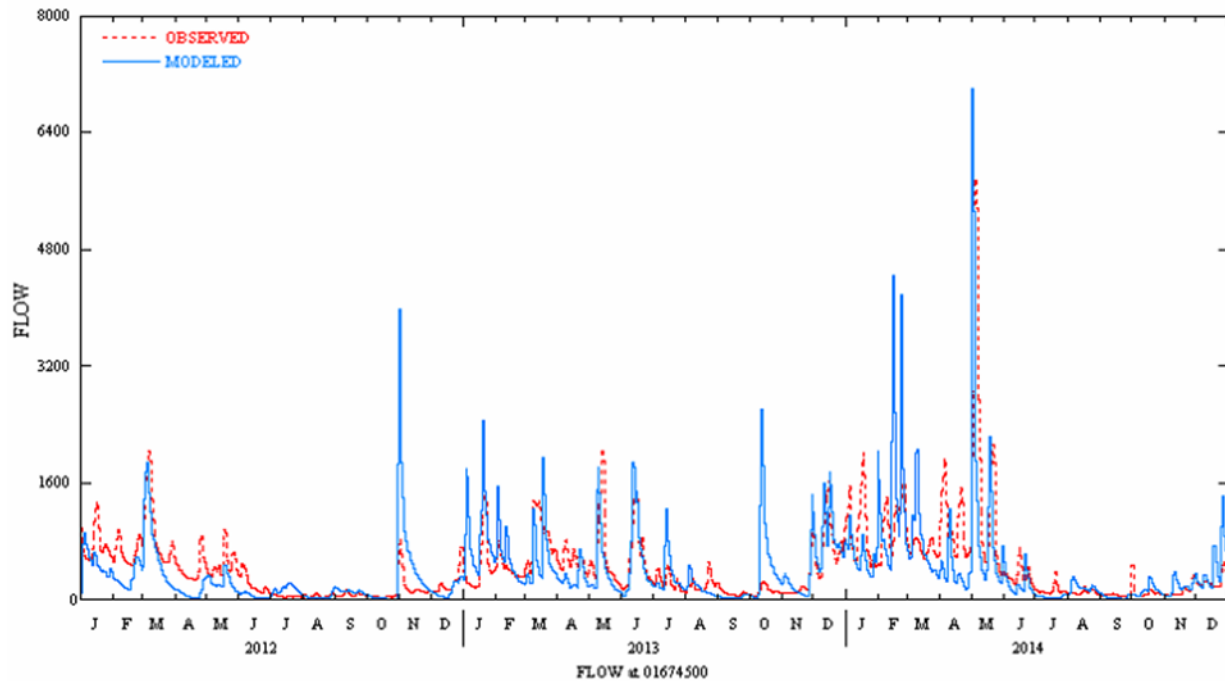


Figure 4-3. The project area HSPF model hydrologic validation results at USGS Station 01674500

#### 4.3.4 Water Quality Model Setup

The HSPF model was set up for fecal coliform bacteria despite the ultimate utilization of the model results in the development of *E. coli* TMDLs. The modeled fecal coliform concentrations were transformed to *E. coli* concentrations employing the following equation as per DEQ guidelines:

$$\log_2 EC = -0.0172 + 0.91905 * \log_2 FC$$

where, EC = *E. coli* concentration (counts/100 ml) and

FC = Fecal coliform bacteria concentration (counts/100 ml)

As significant data and literature information can be found to characterize the accumulation and wash-off of fecal coliform from different nonpoint sources, the watershed model was set up for fecal coliform bacteria. The potential sources for fecal coliform bacteria in the project area, as discussed in Section 2 Watershed Characterization, were utilized in setting up the HSPF water quality model.

#### *4.3.4.1 4.3.4.1 Permitted Discharge Facilities*

All permitted facilities were assumed to be constant sources discharging at their average flow for the hydrologic calibration and validation of the model. Average discharge rate, as obtained from the Discharge Monitoring Report (DMR) data, was considered as the representative flow for each permitted facility and utilized in hydrologic modeling. The DMR data from only one facility (permit number VA0023329) reported *E. coli* bacteria concentrations in the effluent. The bacteria load from this facility was calculated and considered as a point source input during the water quality calibration and validation of the model.

#### *4.3.4.2 4.3.4.2 Nonpoint Sources*

Bacteria loads from nonpoint sources are usually presented in the HSPF model by imparting suitable accumulation, decay, and wash-off rates from the urban sources including pets, agricultural activities and land uses, wildlife sources, and direct deposition from livestock at animal access points to streams, wildlife and failed septic systems and straight pipes. The Fecal Tool, a spreadsheet based template, was utilized to estimate the initial bacteria accumulation rates for the modeled land use categories based on the pollutant source data discussed in Section 3 Pollutant Sources.

##### *4.3.4.2.1 Failed Septic Systems*

In the HSPF model, estimated failed septic systems in the subwatersheds were presented as either direct or land based sources based on their proximity to the impaired streams. A failed septic system was considered a direct source if situated within a 200-foot stream buffer zone, otherwise it was considered to be a land-based source. The product of the number of households within the 200-foot stream-buffer and the percentage of households that use septic systems provided the number of septic systems within the stream buffer zone. On average, three percent of the failed septic systems discharge directly to streams.

##### *4.3.4.2.2 Livestock*

Contribution of livestock to the bacteria load is usually presented as nonpoint source in the model. Only direct depositions occurring at animal access points along the streams are treated as point source loads for modeling purposes. This way, the model accounts for bacteria directly deposited in the stream, deposited while livestock are in confinement and later spread onto

pasturelands in the watershed, and land-based bacteria deposited by livestock while grazing. Horses and ponies are determined to be the predominant kind of livestock, using the inventory of livestock in these regions. No confined animal feeding operations of beef cattle exist in the project area.

The estimated amount of time that each kind of livestock spends on the surrounding land areas and the time they spend in streams was used as a basis for determining the distribution between direct and indirect loading. The direct fecal coliform load was calculated by multiplying the quantity of each type of livestock in each subwatershed by the fecal coliform production per animal per day, and by the percentage of time each animal spends in streams. The land-based load of fecal coliform from livestock while grazing was determined from the number of livestock in each subwatershed, the daily fecal coliform production per animal, and the percent of time spent on pasture. The schedules of beef and dairy cattle providing the basis for estimating the accumulation rates are shown in Table 3-12 and Table 3-13.

#### *4.3.4.2.3 Land Application of Manure*

Beef cattle and horses being the significant sources of manure in the TMDL watersheds, the following assumptions were made:

- Beef cattle and horses spend the majority of their time on pastureland and are not confined.
- Manure generated by beef cattle and horses is applied to pastureland in the watershed
- Daily produced manure is treated as an indirect source in the development of the TMDLs.

Fecal coliform load from beef cattle and horses was taken into account through the methods indicated above.

#### *4.3.4.2.4 Wildlife*

Estimation for fecal loading from wildlife followed procedures similar to livestock fecal loading estimations and indirect and direct fecal coliform contributions were approximated. Estimates of wildlife time spent on the land versus in the stream were utilized as a basis for the distribution between the indirect and direct NPS loads.

Daily fecal coliform production per animal and the amount of time wildlife spend in-stream were added to the Fecal Tool, using literature values and wildlife estimates by subwatershed as the basis. The product of fecal coliform production per animal per day, the number of each type of wildlife in the subwatershed, and the percentage of time each type of animal spends in a stream results in the value of direct deposition of fecal coliform. Indirect (land-based) fecal coliform loading was computed by multiplying the number of each type of wildlife in the watershed, the fecal coliform production per animal per day, and the percentage of time each animal spends on land within the watersheds. The resulting fecal coliform load was then distributed among various land uses that are considered part of the habitat of each type of wildlife. Average unit area load (counts/acre/day) by land use was computed by adding the indirect fecal coliform load to the loads from other sources and incorporated in the model as accumulation rates.

#### 4.3.4.2.5 *Pets*

Bacteria load from pet waste was considered to be a land-based load deposited in residential areas of the project area. The daily fecal coliform loads from pets were determined by multiplying the number of pets by their respective daily fecal coliform production rates and then combining the loads from both the sources.

#### 4.3.5 Fecal Coliform Die-off Rates

The HSPF model developed for the lower Mattaponi River project area includes fecal coliform decay rates. The fecal coliform die-off rates needed by the model are mentioned below:

1. On-Surface Fecal Coliform Die-Off. Fecal coliform undergoes decay prior to being washed into streams, while deposited on land surfaces. The die-off on land is accounted for by setting a limit on the bacteria accumulation. The maximum accumulation value is represented by a model parameter, SQOLIM, which is determined through model calibration.
2. In-Stream Fecal Coliform Die-Off. Fecal coliform will experience decay when directly deposited into the stream and also when entering the stream from indirect sources.

The in-stream fecal coliform die-off rates for were computed from daily decay rates of 1.152 (USEPA, 1985).

#### 4.3.6 Water Quality Calibration and Validation

Water quality calibration of the HSPF model is comprised of the adjustment of model parameters for controlling bacteria accumulation, die-off, wash-off, and transport together with different flow components (e.g. surface runoff, interflow, and base flow and the shape of the hydrographs) and making simulated values match observed flow conditions during the desired calibration period.

Water quality calibration was executed by comparing modeled bacteria concentrations with the observed data. In this iterative process, the model results are compared to the existing in-stream data and the model parameters are adjusted until there is an acceptable agreement between the observed and simulated in-stream concentrations and the build-up and wash-off rates are within the acceptable ranges.

The determination of calibration and validation periods for the model depends on the availability of water quality data and the period of available data. Model calibration and validation utilized the DEQ monitoring stations that were used in the 2016 and 2018 305(b)/303(d) Water Quality Assessment Integrated Reports (VADEQ, 2018a and VADEQ, 2019) for impairment listing. The data for the period January 1, 2010 to December 31, 2017 were employed for calibration and validation.

Modeled fecal coliform concentrations were converted to *E. coli* concentrations before carrying out any direct comparison between the two data sets. For the impaired reaches, the modeled *E. coli* concentrations were compared with the observed data from the water quality monitoring stations on the impaired streams. Table 4-8 demonstrates the observed and modeled geometric mean and rate of exceedance of maximum assessment criterion. The time series plots of observed and modeled concentrations for the calibration at the 12 impaired non-tidal segments are included in Appendix C. Except for a few differences between modeled and observed geometric mean (GM) and exceedance of the STV criterion, the calculated GM and exceedance of STV criterion values of modeled *E. coli* concentrations at the impaired segments matched the observed values reasonably well. The differences between observed and modeled exceedance of the STV criterion in some cases are amplified due to the changes in water quality standards. Except for the bacteria accumulation rate (ACQOP) and the maximum accumulation (SQOLIM), all other water quality variables had the same values at all the water quality monitoring stations.

The values of ACQOP and SQOLIM depended directly on bacteria sources and, therefore, they were considered model input and not calibration parameters. Five water quality stations have multiple years of observed data. The data was sufficient to split into two independent periods (2014-2017 and 2010-2013) to compare with model results and perform water quality calibration and validation. In the water quality calibration period (2014-2017) the model was run iteratively and parameter values adjusted until an acceptable agreement between model output and observed data was reached. The final set of parameter values was then used for model validation and modeling the TMDL allocation scenarios. The model results for the water quality validation period (2010-2013) were compared with the observed data at each of the five stations to ensure that the results of the calibrated model are dependable in times other than the calibration period. Five water quality stations have multiple years observed data and the same set of water quality parameters values was used at all the sites, the comparison of modeled and observed data at those five sites may be considered as the water quality validation. This approach of using a long-term simulation period (e.g. four-year) from multiple stations for water quality calibration (2014 - 2017) and validation (2010 - 2013) was considered a better approach.

*Table 4-8. Comparison of modeled and observed geometric mean and the rate of exceedances of statistical threshold value criterion*

TMDL Watershed	Model Segment	Water Quality Monitoring Station	Geometric Mean Simulated	Geometric Mean Observed	Exceedance of Criterion (410 counts/100 ml) Simulated	Exceedance of Criterion (410 counts/100 ml) Observed
Aylett Creek	286	8-AYL002.27	82	161	20%	18%
Courthouse Creek	203	8-CTH001.96	47	86	19%	6%
Dickeys Swamp	223	8-DKW000.12	66	62	17%	3%
Dogwood Fork	232	8-DWD000.77	59	69	21%	6%
Garnetts Creek	215	8-GNT001.54	88	124	18%	8%
Herring Creek	263	8-HER000.33	96	100	20%	8%
Market Swamp	218	8-MKT001.04	76	89	19%	11%
Mattaponi River	10	8-MPN083.62	68	83	8%	10%
XDN-Garnetts Creek, UT	235	8-XDN000.12	101	196	20%	29%
XJG-Dickeys Swamp, UT	227	8-XJG000.08	91	107	21%	33%
Gravel Run	294	8-GVL000.56	87	203	22%	33%
Dorrell Creek	272	8-DRL000.85	77	154	21%	17%

## 5 TMDL BACTERIA ALLOCATION

---

Total Maximum Daily Load (TMDL) allocation aims to develop the framework to decrease bacteria loads to ensure that water quality standards are met and establish a TMDL equation for each impaired segment. The TMDL, the maximum amount of a pollutant that can be assimilated by a waterbody and still achieve the water quality standard, is the sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for both nonpoint sources and natural background, and a margin of safety (MOS). This definition is denoted by the following equation:

$$\text{TMDL} = \Sigma \text{WLAs} + \Sigma \text{LAs} + \text{MOS}$$

Development of a TMDL is an iterative process that involves modeling and generation of allocation scenarios that meet the water quality criteria. Calibrated models were used to develop various pollutant reduction scenarios and the final TMDL allocation. Each scenario consists of a combination of load reductions from direct deposition and/or land-based bacteria sources. The modeled scenarios provide an insight to the significance of different bacteria sources in each TMDL watershed and TMDL allocation possibilities. The TMDLs were developed based on the Virginia water quality standard for freshwater primary contact recreational use, which states that *E. coli* bacteria shall not exceed a geometric mean of 126 counts/100 ml and shall not have greater than 10% excursion frequency of a statistical threshold value (STV) of 410 counts/100 ml, both in an assessment period of up to 90 days. A five-year simulation (2013-2017) of fecal coliform, which was then converted to *E. coli*, provided the necessary data for TMDL calculations.

Future growth involves planning for future conditions that may require expanding existing WWTPs, building new WWTPs, issuance of new VPDES permits, or accounting for anticipated land conversions (e.g. MS4 expansions) in a TMDL watershed. Because discharges containing bacteria are required by the Virginia Water Quality Standards to meet the applicable water quality criteria at the point of discharge (e.g. end-of-pipe), new and/or expanding VPDES point sources may discharge into a TMDL watershed without a TMDL revision as the VPDES permit will ensure water quality criteria are maintained.

If a TMDL watershed has no existing permitted dischargers or if the existing WLA in the watershed represents 10% or less of the TMDL, the future growth WLA should be 2% of the TMDL; if the existing WLA in the watershed is greater than 10% of the TMDL, the recommended future growth WLA is 1% of the TMDL (VADEQ, 2016a). The former condition applies to each of the non-tidal TMDL watersheds; therefore, the future growth WLA was computed based on the two percent rule. The future growth load for each TMDL watershed was subtracted from the LA and added to the WLA.

### 5.1 Consideration of Seasonal Variations and Critical Conditions

These TMDLs take into account the seasonal variations and critical conditions for stream flow, loading, and water quality parameters. Seasonal variations include changes in stream flow and water quality due to hydrologic and climatological patterns. The seasonal variations of rainfall, runoff, and bacteria wash-off are explicitly incorporated in the long-term models developed for these TMDLs, utilizing an hourly time-step. Also, bacteria accumulation rates were developed on a monthly basis for pasture and cropland to account for its temporal variability. The consideration of critical conditions intends to guarantee that the water quality of impaired streams are protected during their most vulnerable times. Critical conditions bear significance mainly because they describe a combination of factors that cause an exceedance of the water quality criteria. The model results from a continuous simulation spanning over a five-year period were selected to ensure that the TMDL allocations would meet the water quality standards under critical conditions. Both low flow and high flow conditions were included in the simulation period to cover all the flow regimes.

### 5.2 Incorporation of Margin of Safety (MOS)

A MOS is factored into a TMDL in recognition of uncertainties associated with source assessment data, model parameterization, etc. The MOS can be either explicit, as an additional load reduction requirement, or implicit, which involves incorporating conservative assumptions within the application of the TMDL model. An explicit MOS was used in the tidal bacteria TMDLs as an additional 5% load reduction requirement. An implicit MOS was used in the non-tidal bacteria TMDLs by using conservative estimations of all factors that would affect bacteria loadings in the watershed (e.g., animal numbers, bacteria densities, parameters that are used to

characterize manure contributions to the stream). A sample of conservative assumptions and approaches taken during model development that constitute an implicit MOS include:

- Assuming permitted point sources are operating at design flow and permitted limits.
- Incorporating a slight positive bias in the model's water quality calibration by overestimating the contribution of nonpoint sources; i.e., developing a calibrated water quality model with simulated percent exceedances of the assessment and geometric mean criteria higher than observed where practicable.
- Rounding percent reductions from existing loads from each land use category up to the nearest 5% (except when reductions greater than 95% were needed) to calculate the TMDL.

Implementing the above conservative assumptions and approaches ensures that no water quality standard exceedances will occur if the load reductions specified in the TMDL are achieved.

### 5.3 Wasteload Allocation Development

The design flow of existing permitted facilities and a monthly geomean *E. coli* concentration of 126 counts/100 ml are used as the basis of the allocated *E. coli* load for VPDES facilities that are permitted to discharge bacteria. The one VPDES facility permitted to discharge bacteria in the project area discharges to the Herring Creek TMDL Watershed (within VAHU6 YO56).

### 5.4 Load Allocation Development

The reduction in loads from nonpoint sources focuses on anthropogenic sources, including direct deposition from failed septic systems, straight pipes, and livestock as well as land-based sources from urban, residential and pasture agricultural land uses. Although reductions from background sources were not necessary to meet the water quality standards, 100% reduction of direct deposition from wildlife was considered to understand the significance of such background sources. The key load reduction scenarios evaluated for reaching the final TMDL allocations are listed for each TMDL watershed. These scenarios were developed for all impaired segments and are presented in Section 5.5.

## 5.5 Summary of Non-Tidal TMDLs

A summary of non-tidal TMDL allocations by sources, wasteload allocation (WLA), and load allocations (LA) for each impaired non-tidal segment are represented in Sections 5.5.1 through 5.5.12 (tidal impairments are addressed in Section 6). Each section consists of a set of tables that include a list of modeled scenarios, reductions of *E. coli* loads from individual source categories including their existing and allocated loads, and the TMDL equations on the average annual basis as well as the daily maximum basis.

### 5.5.1 Aylett Creek (VAP-F23R\_AYL01A12)

The existing and allocated point and nonpoint source loads along with a TMDL summary for Aylett Creek are presented in this section.

#### 5.5.1.1 Aylett Creek Wasteload Allocation

There are no permitted point sources in the Aylett Creek TMDL watershed; therefore, as outlined in DEQ recommendations (VADEQ, 2016a), two percent of the TMDL was set aside for future growth of developed land and residential human populations. The future growth value ( $2.42\text{E}+11$  counts per year *E. coli*) is assigned as the WLA in the Aylett Creek TMDL watershed.

#### 5.5.1.2 Aylett Creek Load Allocation Plan and TMDL Summary

The scenarios modeled to determine the TMDL allocation for the Aylett Creek TMDL watershed are listed in Table 5-1. No reductions in bacteria loads from forest and wetland were considered in any of the scenarios. According to the TMDL allocation scenario (number 5), the recommended reductions necessary for meeting the *E. coli* GM water quality criterion of 126 counts/100 ml and the statistical threshold value water quality criterion of 410 counts/100 ml for Aylett Creek are:

- 100% reduction of the human sources (failed septic systems and straight pipes)
- 51% reduction of the direct livestock in-stream loading
- 33% reduction of bacteria loading from nonpoint sources (pasture, hay, cropland, and developed land)

*Table 5-1. Bacteria load allocation scenarios for Aylett Creek TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml)*

Scenario	Failing Sewage Systems	Cattle Direct Deposition	Pasture	Hay	Cropland	Developed Land	Wildlife Direct Deposition	GM Exceedance Rate	STV Exceedance Rate
1	100	0	0	0	0	0	0	11	36
2	100	100	0	0	0	0	0	1	31
3	100	100	0	0	0	0	100	0	17
4	100	50	50	50	50	50	0	0	0
<b>5<sup>1</sup></b>	<b>100</b>	<b>51</b>	<b>33</b>	<b>33</b>	<b>33</b>	<b>33</b>	<b>0</b>	<b>0</b>	<b>0</b>

<sup>1</sup>Final TMDL Scenario

Table 5-2 shows the existing condition *E. coli* loads, load allocations under scenario 5 and the reductions required for different land use categories and direct sources within Aylett Creek watershed.

*Table 5-2. Annual load existing conditions and allocations and percent reduction per land use category for Aylett Creek TMDL Watershed*

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Forest and Wetland	3.44E+11	2.8	3.44E+11	0.0
Developed Land	4.77E+11	3.9	3.18E+11	33.4
Hay	1.74E+10	0.1	1.16E+10	33.4
Pasture	5.20E+11	4.2	3.47E+11	33.4
Cropland	1.76E+11	1.4	1.17E+11	33.4
Cattle Direct Deposition	5.78E+09	<0.1	2.83E+09	51.0
Wildlife Direct Deposition	1.07E+13	86.4	1.07E+13	0.0
Straight Pipes, Pit Privies, and Failing Septic Systems	1.48E+11	1.2	0.00E+00	100.0
Point Source	0.00E+00	0.0	0.00E+00	0.0
Future Growth	-	-	2.42E+11	-
Total Loads	1.24E+13	100.0	1.21E+13	2.5

Table 5-3 shows the TMDL, which is the amount of *E. coli* that the stream can receive in a given year while still meeting the water quality standard. The average annual loads were estimated using a five-year (2013-2017) water quality simulation and taking into consideration the hydrologic and environmental processes involving the fate and transport of bacteria. The TMDL WLA reflects a future growth allocation for potential new or expanding dischargers in the future.

Any permittees discharging bacteria will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The Load Allocation is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined at the downstream end of the impaired segment, the watershed outlet. This value may be different from nonpoint source loads provided in Table 5-2 because of factors such as bacteria die-off that occur between the point of deposition and the modeled watershed outlet.

*Table 5-3. Aylett Creek TMDL (counts/year) for E. coli*

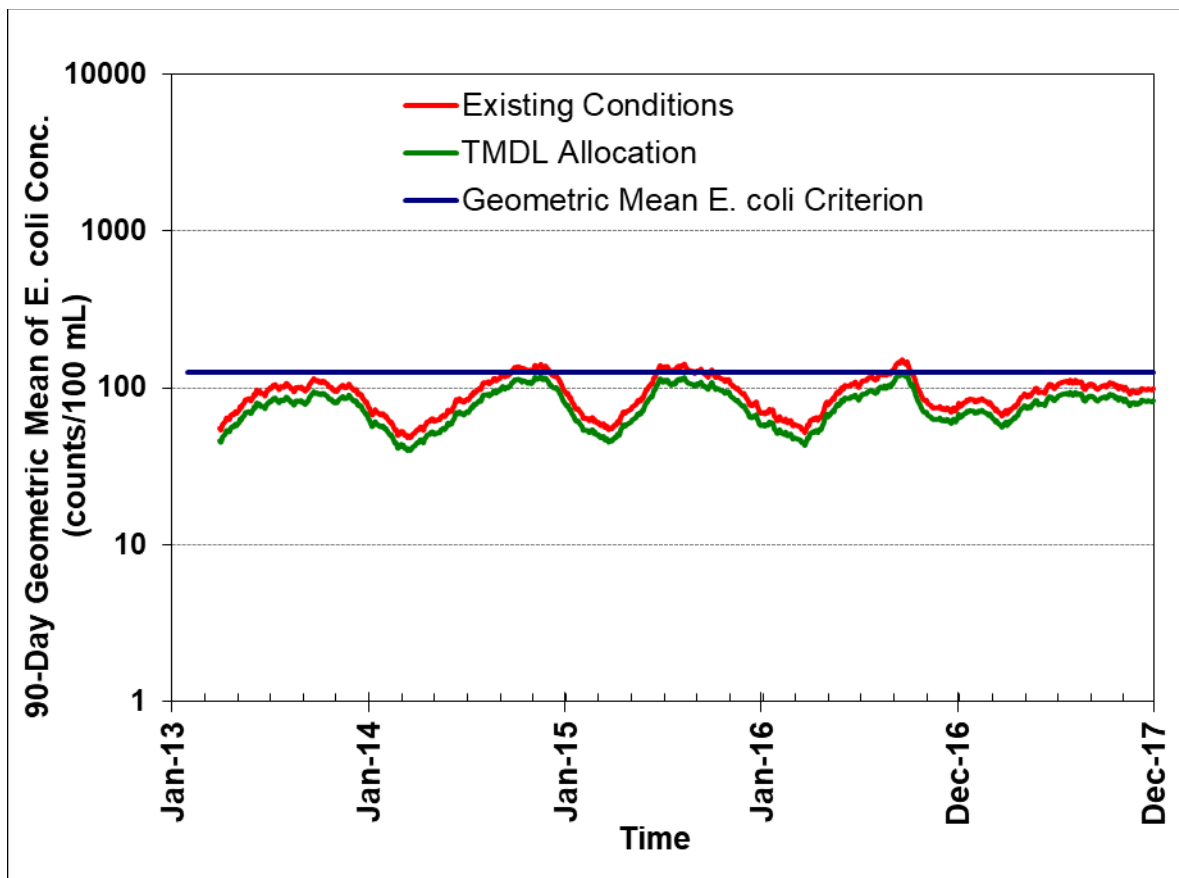
WLA	LA	MOS	TMDL
2.42E+11	1.18E+13	IMPLICIT	1.21E+13

The average annual *E. coli* loads were converted to daily loads using the approach discussed in section 5.6. The TMDL, expressed in daily loads, is given in Table 5-4.

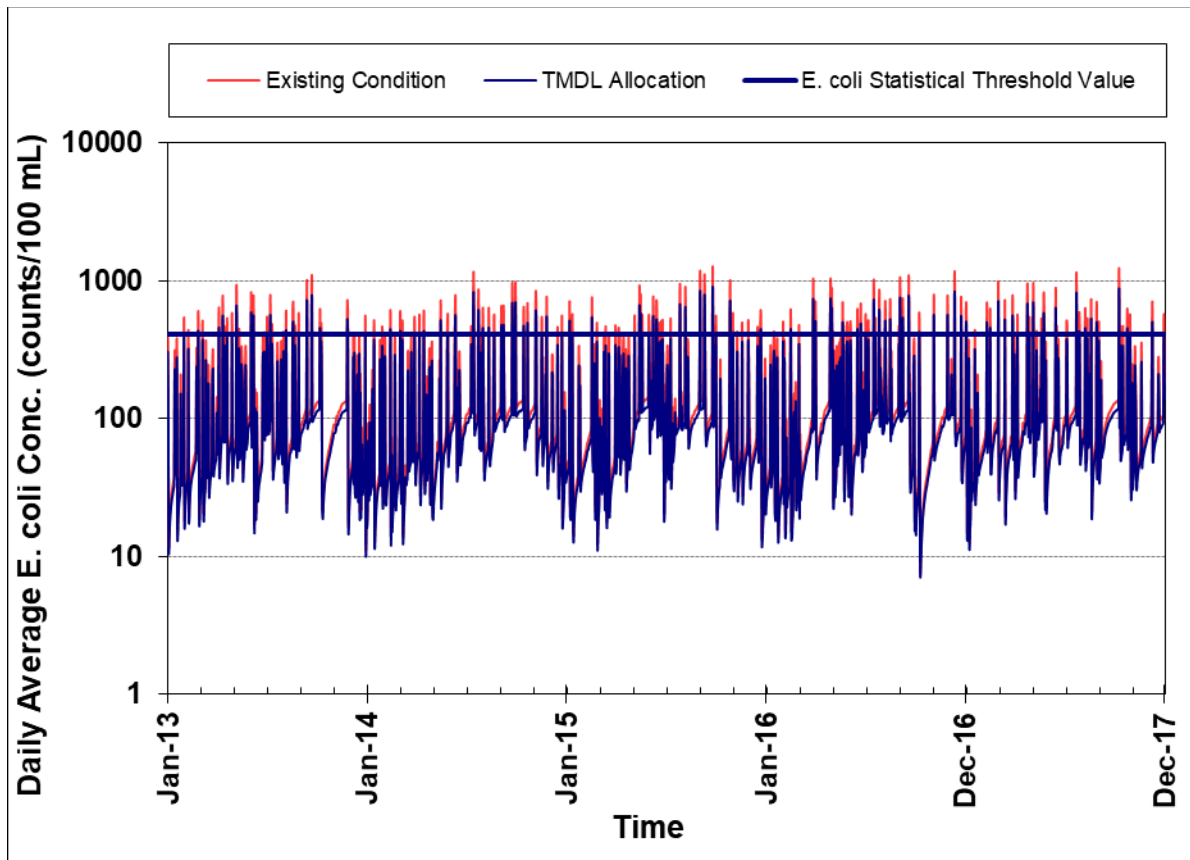
*Table 5-4. Aylett Creek TMDL (counts/day) for E. coli*

WLA	LA	MOS	TMDL
6.62E+08	1.25E+11	IMPLICIT	1.26E+11

Figure 5-1 and Figure 5-2 show the rolling 90-day geometric mean and daily average *E. coli* concentrations, respectively, under both the existing and the TMDL allocation conditions. Figure 5-3 shows the exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions. The figures also include the geometric mean and the statistical threshold value criteria as horizontal solid lines. The figures demonstrate that the developed TMDL ensures that, under the TMDL allocation conditions, both water quality criteria are met in the impaired segment of Aylett Creek.



*Figure 5-1. Aylett Creek 90-day geometric mean E. coli concentrations under existing and TMDL conditions*



*Figure 5-2. Aylett Creek daily average E. coli concentrations under existing and TMDL conditions*

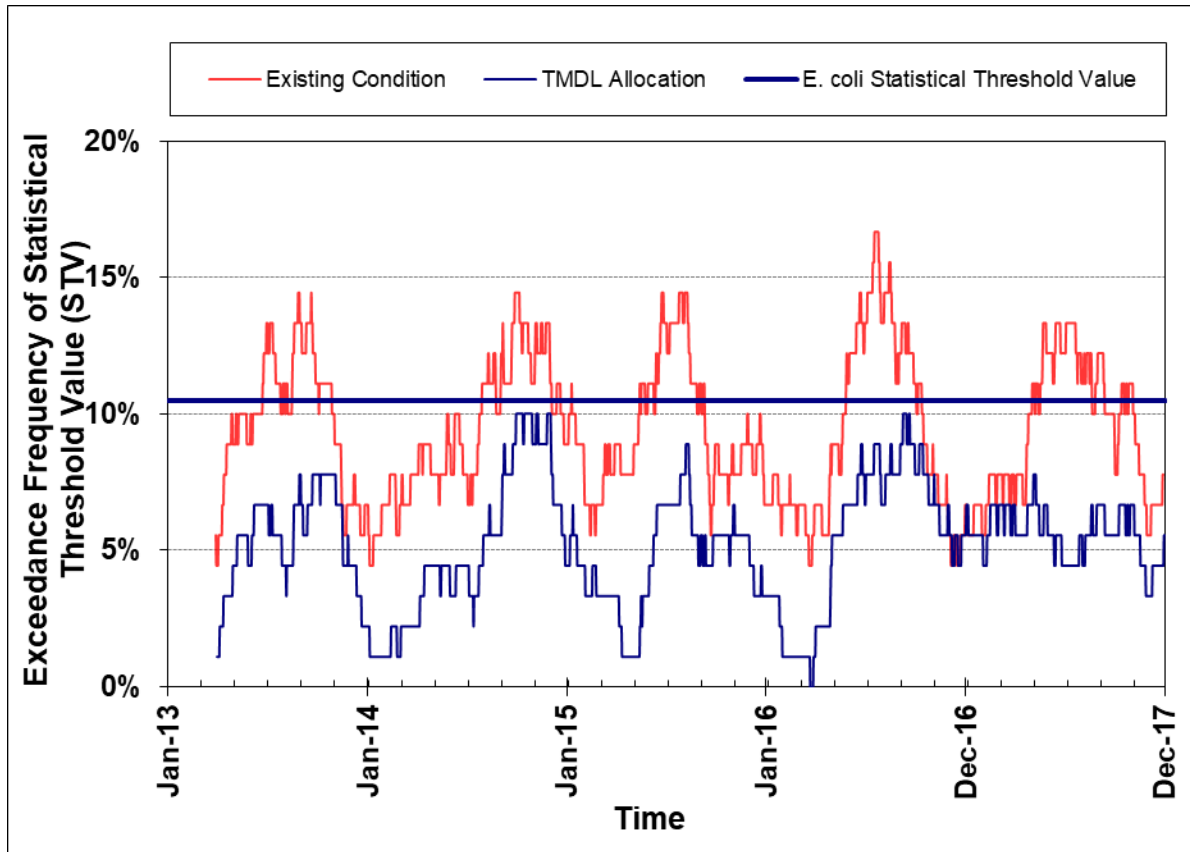


Figure 5-3. Aylett Creek exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions.

### 5.5.2 Courthouse Creek (VAP-F24R\_CTH01A00)

The existing and allocated point and nonpoint source loads along with a TMDL summary for Courthouse Creek are presented in this section.

#### 5.5.2.1 Courthouse Creek Wasteload Allocation

There are no permitted point sources in the Courthouse Creek TMDL watershed; therefore, as outlined in DEQ recommendations (VADEQ, 2016a), two percent of the TMDL was set aside for future growth of developed land and residential human populations. The future growth value (1.41E+11 counts per year *E. coli*) is assigned as the WLA in the Courthouse Creek TMDL watershed.

### 5.5.2.2 Courthouse Creek Load Allocation Plan and TMDL Summary

The scenarios modeled to determine the TMDL allocation for the Courthouse Creek TMDL watershed are listed in Table 5-5. No reductions in bacteria loads from forest and wetland were considered in any of the scenarios. According to the TMDL allocation scenario (number 5), the recommended reductions necessary for meeting the *E. coli* GM water quality criterion of 126 counts/100 ml and the statistical threshold value water quality criterion of 410 counts/100 ml for Courthouse Creek are:

- 100% reduction of the human sources (failed septic systems and straight pipes)
- 31% reduction of the direct livestock in-stream loading
- 17% reduction of bacteria loading from nonpoint sources (pasture, hay, cropland, and developed land)

*Table 5-5. Bacteria load allocation scenarios for Courthouse Creek TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml)*

Scenario	Failing Sewage Systems	Cattle Direct Deposition	Pasture	Hay	Cropland	Developed Land	Wildlife Direct Deposition	GM Exceedance Rate	STV Exceedance Rate
1	100	0	0	0	0	0	0	0	15
2	100	100	0	0	0	0	0	0	15
3	100	100	0	0	0	0	100	0	3
4	100	50	50	50	50	50	0	0	0
<b>5<sup>1</sup></b>	<b>100</b>	<b>31</b>	<b>17</b>	<b>17</b>	<b>17</b>	<b>17</b>	<b>0</b>	<b>0</b>	<b>0</b>

<sup>1</sup>Final TMDL Scenario

Table 5-6 shows the existing condition *E. coli* loads, load allocations under scenario 5 and the reductions required for different land use categories and direct sources within Courthouse Creek watershed.

*Table 5-6. Annual load existing conditions and allocations and percent reduction per land use category for Courthouse Creek TMDL Watershed*

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Forest and Wetland	4.54E+11	6.3	4.54E+11	0.0
Developed Land	3.75E+11	5.2	3.08E+11	17.7
Hay	2.72E+10	0.4	2.24E+10	17.7

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Pasture	1.20E+12	16.5	9.85E+11	17.7
Cropland	3.37E+11	4.6	2.78E+11	17.7
Cattle Direct Deposition	8.76E+09	0.1	6.01E+09	31.4
Wildlife Direct Deposition	4.86E+12	66.9	4.86E+12	0.0
Straight Pipes, Pit Privies, and Failing Septics	1.10E+09	0.0	0.00E+00	100.0
Point Source	0.00E+00	0.0	0.00E+00	0.0
Future Growth	-	-	1.41E+11	-
Total Loads	7.26E+12	100.0	7.05E+12	2.8

Table 5-7 shows the TMDL, which is the amount of *E. coli* that the stream can receive in a given year while still meeting the water quality standard. The average annual loads were estimated using a five-year (2013-2017) water quality simulation and taking into consideration the hydrologic and environmental processes involving the fate and transport of bacteria. The TMDL WLA reflects a future growth allocation for potential new or expanding dischargers in the future. Any permittees discharging bacteria in the project area will include bacteria effluent limits in accordance with applicable permit guidance to ensure that the discharge meets the primary contact recreation use bacteria criteria. The Load Allocation is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined at the downstream end of the impaired segment, the watershed outlet. This value may be different from nonpoint source loads provided in Table 5-6 because of factors such as bacteria die-off that occur between the point of deposition and the modeled watershed outlet.

*Table 5-7. Courthouse Creek TMDL (counts/year) for E. coli*

WLA	LA	MOS	TMDL
1.41E+11	6.91E+12	IMPLICIT	7.05E+12

The average annual *E. coli* loads were converted to daily loads using the approach discussed in section 5.6. The TMDL, expressed in daily loads, is given in Table 5-8.

*Table 5-8. Courthouse Creek TMDL (counts/day) for E. coli*

WLA	LA	MOS	TMDL
3.86E+08	7.25E+10	IMPLICIT	7.29E+10

Figure 5-4 and Figure 5-5 show the 90-day geometric mean and daily average *E. coli* concentrations, respectively, under both the existing and the TMDL allocation conditions. Figure 5-6 shows the exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions. The figures also include the geometric mean and the statistical threshold value criteria as horizontal solid lines. The figures demonstrate that the developed TMDL ensures that, under the TMDL allocation conditions, both water quality criteria are met in the impaired segment of Courthouse Creek.

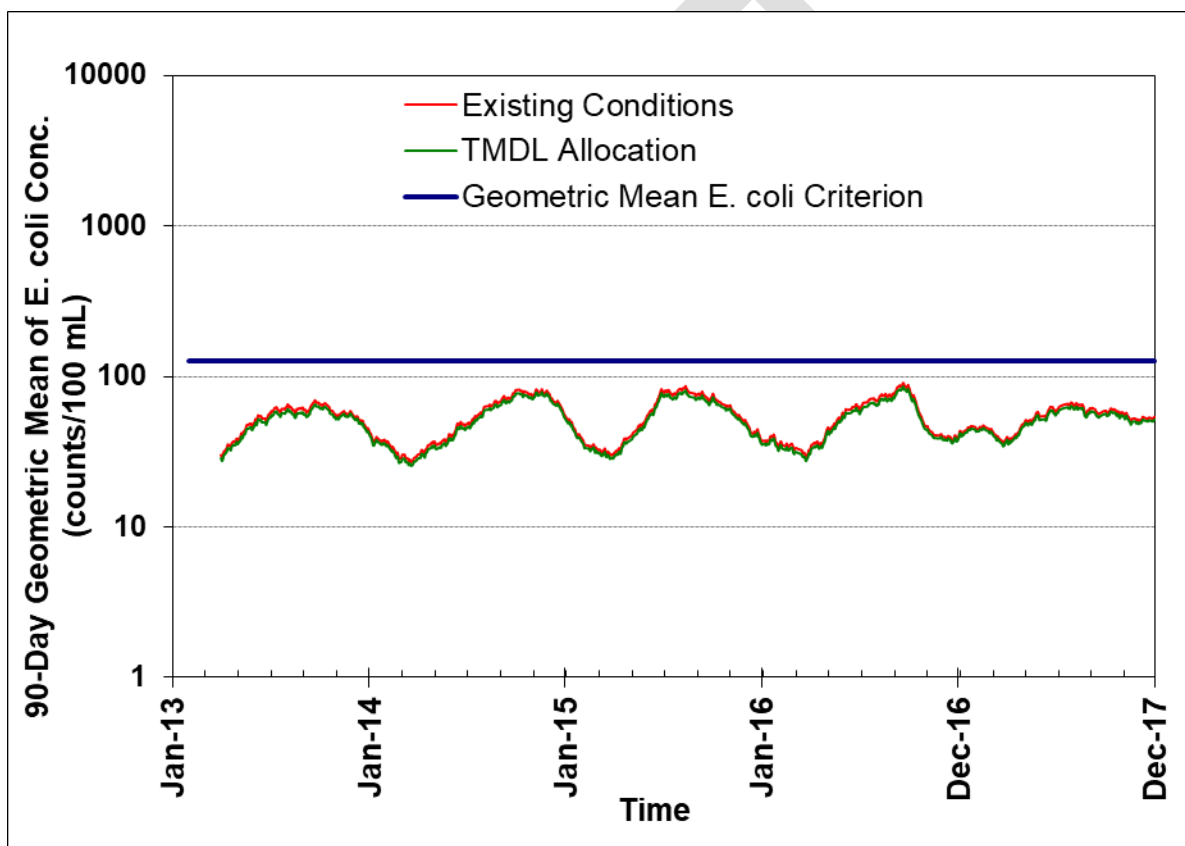
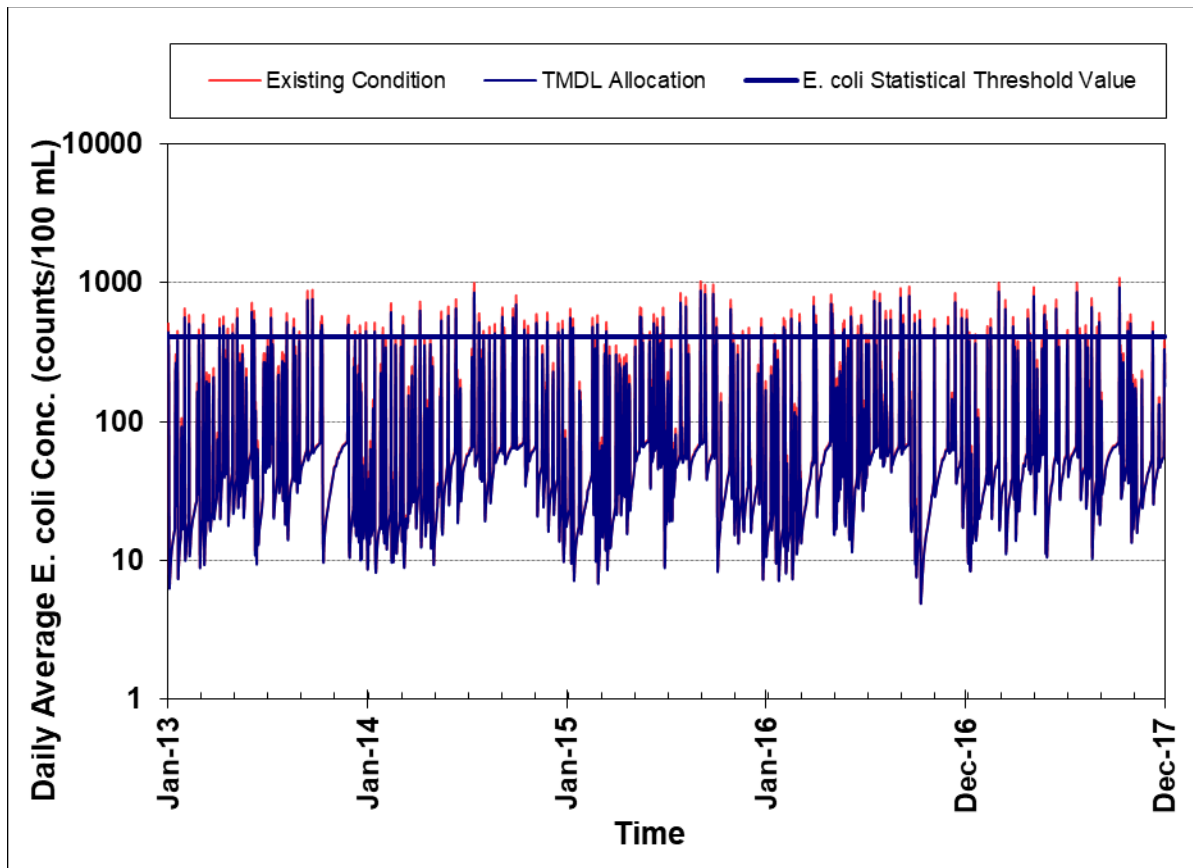
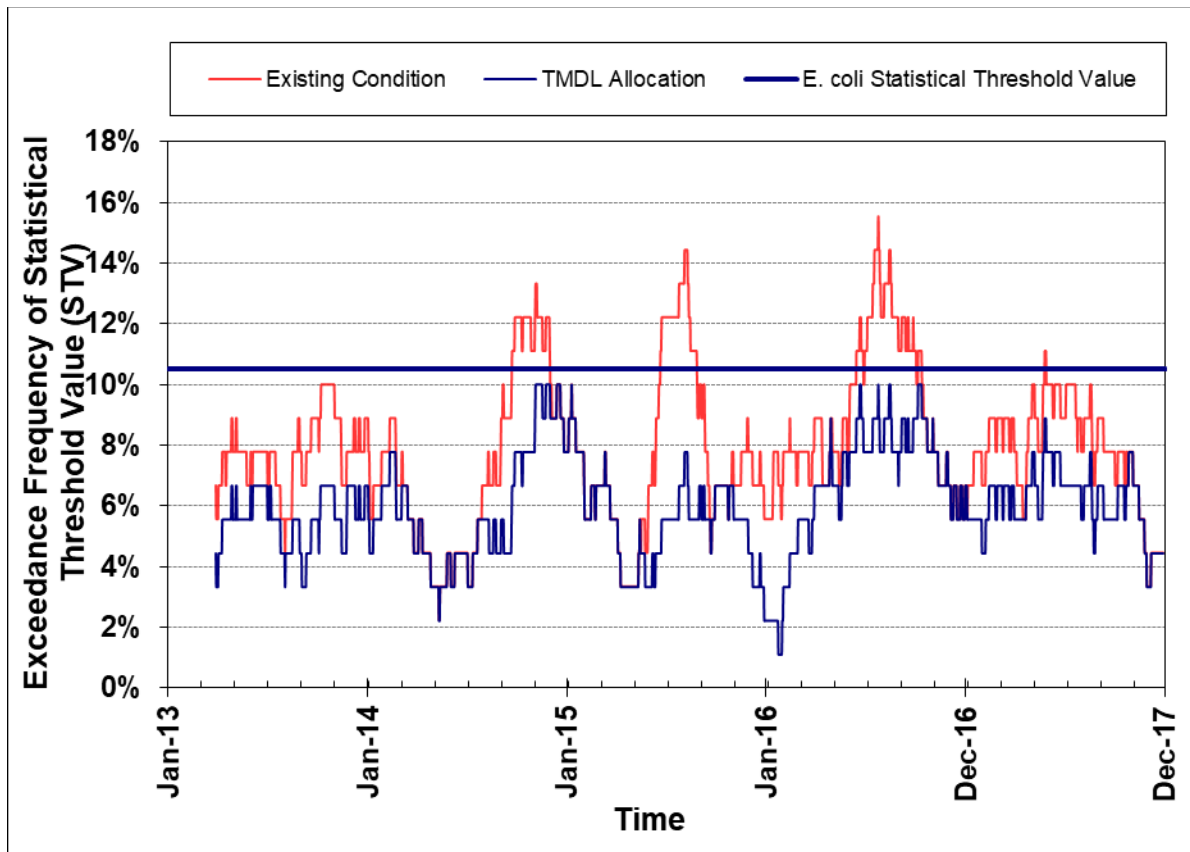


Figure 5-4. Courthouse Creek the rolling 90-Day geometric mean *E. coli* concentrations under existing and TMDL conditions



*Figure 5-5. Courthouse Creek daily average E. coli concentrations under existing and TMDL conditions*



*Figure 5-6. Courthouse Creek exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions*

### 5.5.3 Dickeys Swamp (VAP-F23R\_DKW01B00)

The existing and allocated point and nonpoint source loads along with a TMDL summary for Dickeys Swamp are presented in this section.

#### 5.5.3.1 Dickeys Swamp Wasteload Allocation

There are no permitted point sources in the Dickeys Swamp TMDL watershed; therefore, as outlined in DEQ recommendations (VADEQ, 2016a), two percent of the TMDL was set aside for future growth of developed land and residential human populations. The future growth value (2.22E+11 counts per year *E. coli*) is assigned as the WLA in the Dickeys Swamp TMDL watershed.

### 5.5.3.2 Dickey's Swamp Load Allocation Plan and TMDL Summary

The scenarios modeled to determine the TMDL allocation for the Dickey's Swamp TMDL watershed are listed in Table 5-9. No reductions in bacteria loads from forest and wetland were considered in any of the scenarios. According to the TMDL allocation scenario (number 5), the recommended reductions necessary for meeting the *E. coli* GM water quality criterion of 126 counts/100 ml and the statistical threshold value water quality criterion of 410 counts/100 ml for Dickey's Swamp are:

- 100% reduction of the human sources (failed septic systems and straight pipes)
- 31% reduction of the direct livestock in-stream loading
- 28% reduction of bacteria loading from nonpoint sources (pasture, hay, cropland, and developed land)

*Table 5-9. Bacteria load allocation scenarios for Dickey's Swamp TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml)*

Scenario	Failing Sewage Systems	Cattle Direct Deposition	Pasture	Hay	Cropland	Developed Land	Wildlife Direct Deposition	GM Exceedance Rate	STV Exceedance Rate
1	100	0	0	0	0	0	0	1	13
2	100	100	0	0	0	0	0	1	13
3	100	100	0	0	0	0	100	0	5
4	100	50	50	50	50	50	0	0	0
<b>5<sup>1</sup></b>	<b>100</b>	<b>31</b>	<b>28</b>	<b>28</b>	<b>28</b>	<b>28</b>	<b>0</b>	<b>0</b>	<b>0</b>

<sup>1</sup>Final TMDL Scenario

Table 5-10 shows the existing condition *E. coli* loads, load allocations under scenario 5 and the reductions required for different land use categories and direct sources within Dickey's Swamp watershed.

*Table 5-10. Annual load existing conditions and allocations and percent reduction per land use category for Dickey's Swamp TMDL Watershed*

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Forest and Wetland	3.15E+12	27.1	3.15E+12	0.0
Developed Land	5.97E+11	5.1	4.27E+11	28.5

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Hay	8.32E+10	0.7	5.95E+10	28.5
Pasture	1.42E+12	12.2	1.01E+12	28.5
Cropland	5.31E+11	4.6	3.80E+11	28.5
Cattle Direct Deposition	6.62E+09	0.1	4.54E+09	31.4
Wildlife Direct Deposition	5.83E+12	50.2	5.83E+12	0.0
Straight Pipes, Pit Privies, and Failing Septics	3.76E+09	0.0	0.00E+00	100.0
Point Source	0.00E+00	0.0	0.00E+00	0.0
Future Growth	-	-	2.22E+11	0
Total Loads	1.16E+13	100.0	1.11E+13	4.6

Table 5-11 shows the TMDL, which is the amount of *E. coli* that the stream can receive in a given year while still meeting the water quality standard. The average annual loads were estimated using a five-year (2013-2017) water quality simulation and taking into consideration the hydrologic and environmental processes involving the fate and transport of bacteria. The TMDL WLA reflects a future growth allocation for potential new or expanding dischargers in the future. Any permittees discharging bacteria will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The Load Allocation is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined at the downstream end of the impaired segment, the watershed outlet. This value may be different from nonpoint source loads provided in Table 5-10 because of factors such as bacteria die-off that occur between the point of deposition and the modeled watershed outlet.

*Table 5-11. Dickey's Swamp TMDL (counts/year) for E. coli*

WLA	LA	MOS	TMDL
2.22E+11	1.09E+13	IMPLICIT	1.11E+13

The average annual *E. coli* loads were converted to daily loads using the approach discussed in section 5.6. The TMDL, expressed in daily loads, is given in Table 5-12.

Table 5-12. Dickey's Swamp TMDL (counts/day) for *E. coli*

WLA	LA	MOS	TMDL
6.07E+08	1.15E+11	IMPLICIT	1.15E+11

Figure 5-7 and Figure 5-8 show the 90-day geometric mean and daily average *E. coli* concentrations, respectively, under both the existing and the TMDL allocation conditions. Figure 5-9 shows the exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions. The figures also include the geometric mean and the statistical threshold value criteria as horizontal solid lines. The figures demonstrate that the developed TMDL ensures that, under the TMDL allocation conditions, both water quality criteria are met in the impaired segment of Dickey's Swamp.

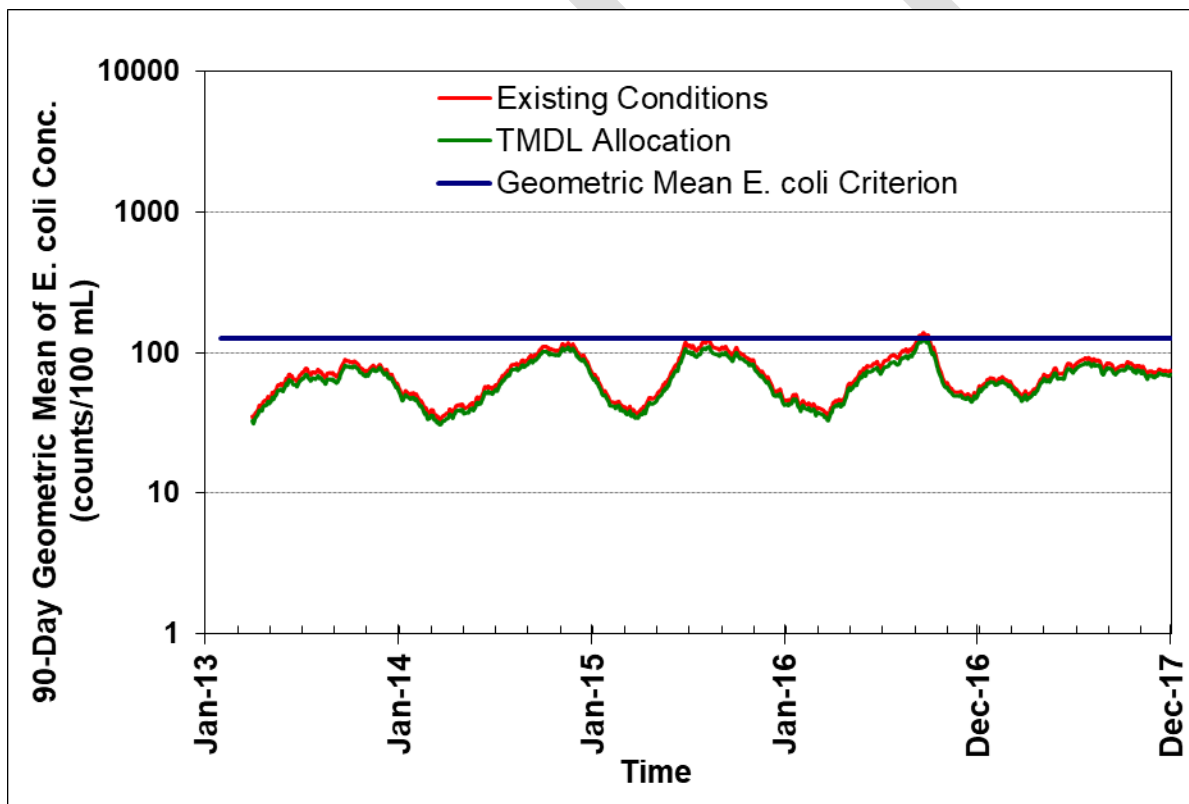
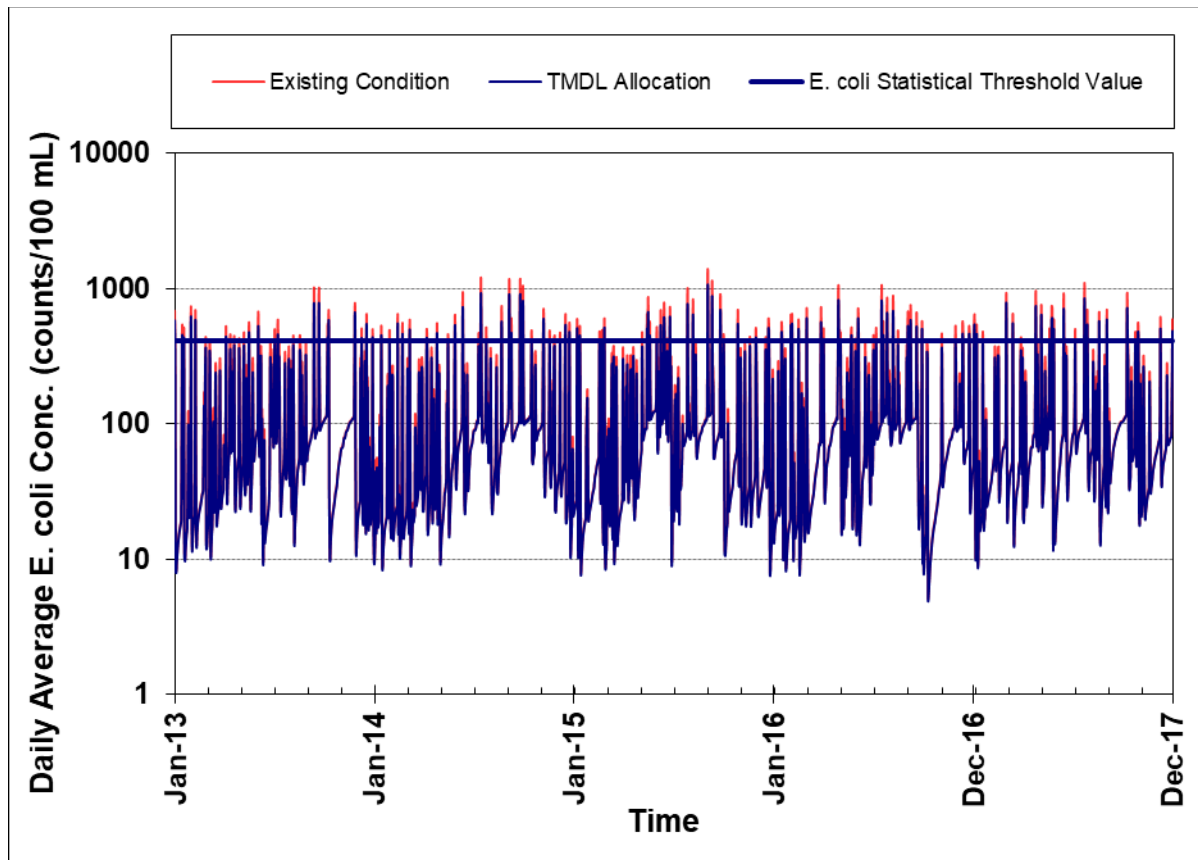
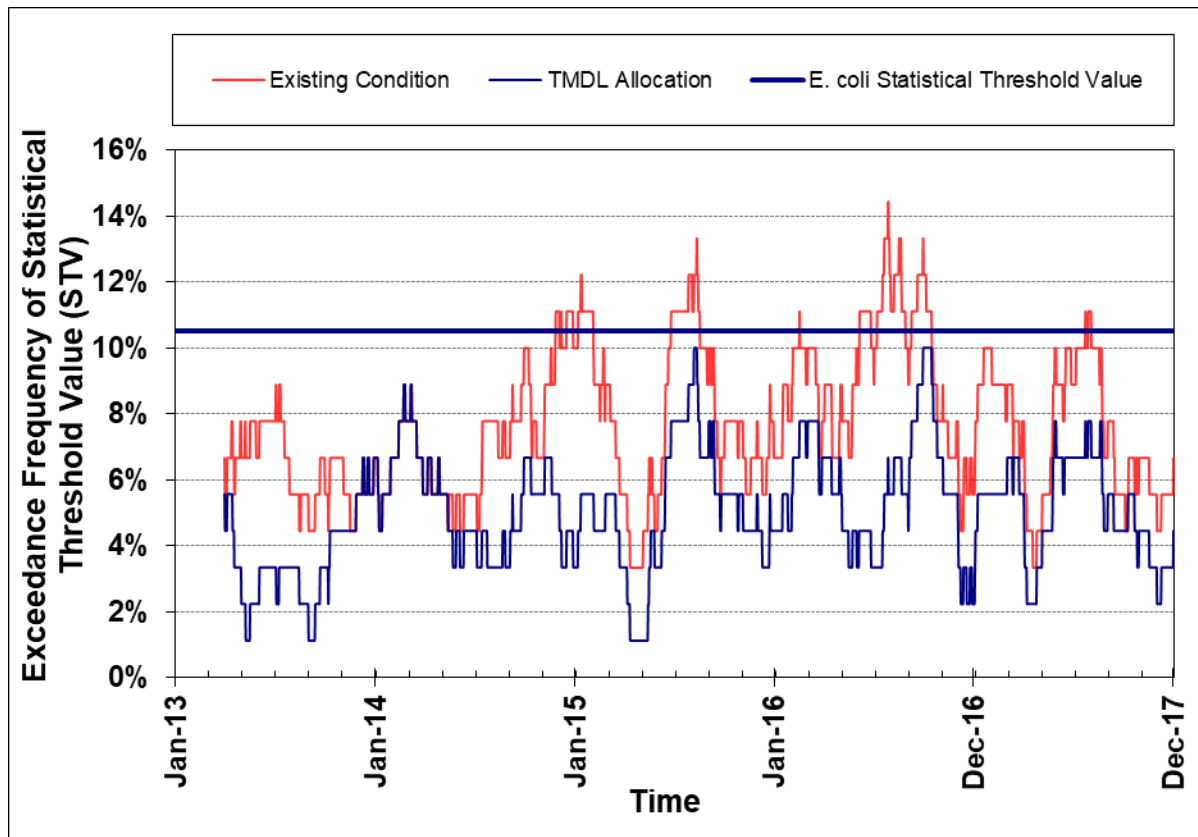


Figure 5-7. Dickey's Swamp the rolling 90-day geometric mean *E. coli* concentrations under existing and TMDL conditions



*Figure 5-8. Dickeys Swamp daily average E. coli concentrations under existing and TMDL conditions*



*Figure 5-9. Dickey's Swamp exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions*

#### 5.5.4 Dogwood Fork (VAP-F23R\_DWD01A00)

The existing and allocated point and nonpoint source loads along with a TMDL summary for Dogwood Fork are presented in this section.

##### *5.5.4.1 Dogwood Fork Wasteload Allocation*

There are no permitted point sources in the Dogwood Fork TMDL watershed; therefore, as outlined in DEQ recommendations (VADEQ, 2016a), two percent of the TMDL was set aside for future growth of developed land and residential human populations. The future growth value ( $1.79\text{E}+10$  counts per year *E. coli*) is assigned as the WLA in the Dogwood Fork TMDL watershed.

#### 5.5.4.2 Dogwood Fork Load Allocation Plan and TMDL Summary

The scenarios modeled to determine the TMDL allocation for the Dogwood Fork TMDL watershed are listed in Table 5-13. No reductions in bacteria loads from forest and wetland were considered in any of the scenarios. According to the TMDL allocation scenario (number 5), the recommended reductions necessary for meeting the *E. coli* GM water quality criterion of 126 counts/100 ml and the statistical threshold value water quality criterion of 410 counts/100 ml for Dogwood Fork are:

- 100% reduction of the human sources (failed septic systems and straight pipes)
- 31% reduction of the direct livestock in-stream loading
- 32% reduction of bacteria loading from nonpoint sources (pasture, hay, cropland, and developed land)

*Table 5-13. Bacteria load allocation scenarios for Dogwood Fork TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml)*

Scenario	Failing Sewage Systems	Cattle Direct Deposition	Pasture	Hay	Cropland	Developed Land	Wildlife Direct Deposition	GM Exceedance Rate	STV Exceedance Rate
1	100	0	0	0	0	0	0	0	23
2	100	100	0	0	0	0	0	0	23
3	100	100	0	0	0	0	100	0	9
4	100	50	50	50	50	50	0	0	0
<b>5<sup>1</sup></b>	<b>100</b>	<b>31</b>	<b>32</b>	<b>32</b>	<b>32</b>	<b>32</b>	<b>0</b>	<b>0</b>	<b>0</b>

<sup>1</sup>Final TMDL Scenario

Table 5-14 shows the existing condition *E. coli* loads, load allocations under scenario 5 and the reductions required for different land use categories and direct sources within Dogwood Fork watershed.

*Table 5-14. Annual load existing conditions and allocations and percent reduction per land use category for Dogwood Fork TMDL Watershed*

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Forest and Wetland	7.90E+10	7.1	7.90E+10	0.0
Developed Land	1.49E+11	13.3	1.00E+11	32.4
Hay	3.59E+10	3.2	2.42E+10	32.4

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Pasture	2.96E+11	26.5	2.00E+11	32.4
Cropland	2.33E+11	20.8	1.57E+11	32.4
Cattle Direct Deposition	2.60E+10	2.3	1.79E+10	31.4
Wildlife Direct Deposition	3.00E+11	26.8	3.00E+11	0.0
Straight Pipes, Pit Privies, and Failing Septic Systems	0.00E+00	0.0	0.00E+00	100.0
Point Source	0.00E+00	0.0	0.00E+00	0.0
Future Growth	0.00E+00	0.0	1.79E+10	-
Total Loads	1.12E+12	100.0	8.97E+11	19.8

Table 5-15 shows the TMDL, which is the amount of *E. coli* that the stream can receive in a given year while still meeting the water quality standard. The average annual loads were estimated using a five-year (2013-2017) water quality simulation and taking into consideration the hydrologic and environmental processes involving the fate and transport of bacteria. The TMDL WLA reflects a future growth allocation for potential new or expanding dischargers in the future. Any permittees discharging bacteria will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The Load Allocation is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined at the downstream end of the impaired segment, the watershed outlet. This value may be different from nonpoint source loads provided in Table 5-14 because of factors such as bacteria die-off that occur between the point of deposition and the modeled watershed outlet.

*Table 5-15. Dogwood Fork TMDL (counts/year) for E. coli*

WLA	LA	MOS	TMDL
1.79E+10	8.79E+11	IMPLICIT	8.97E+11

The average annual *E. coli* loads were converted to daily loads using the approach discussed in section 5.6. The TMDL, expressed in daily loads, is given in Table 5-16.

*Table 5-16. Dogwood Fork TMDL (counts/day) for E. coli*

WLA	LA	MOS	TMDL
4.91E+07	9.27E+09	IMPLICIT	9.32E+09

Figure 5-10 and Figure 5-11 show the 90-day geometric mean and daily average *E. coli* concentrations, respectively, under both the existing and the TMDL allocation conditions. Figure 5-12 shows the exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions. The figures also include the geometric mean and the statistical threshold value criteria as horizontal solid lines. The figures demonstrate that the developed TMDL ensures that, under the TMDL allocation conditions, both water quality criteria are met in the impaired segment of Dogwood Fork.

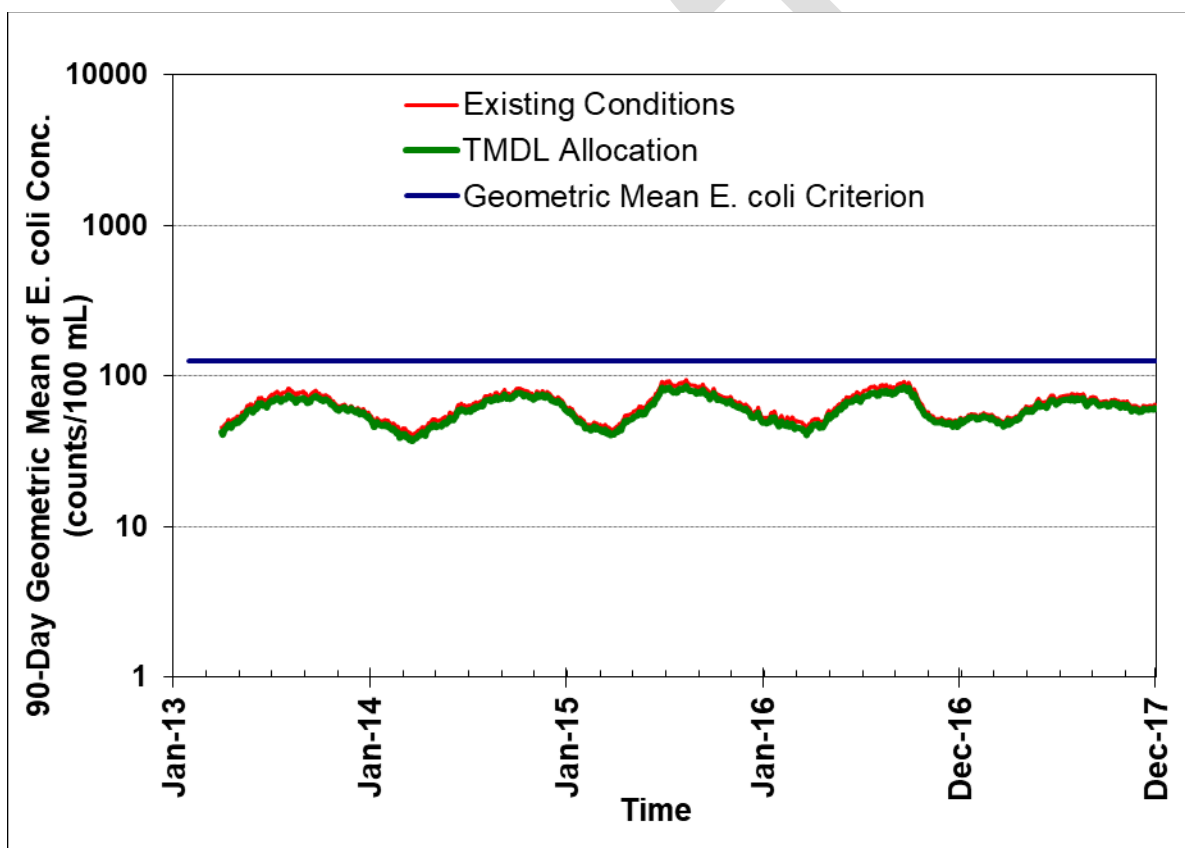
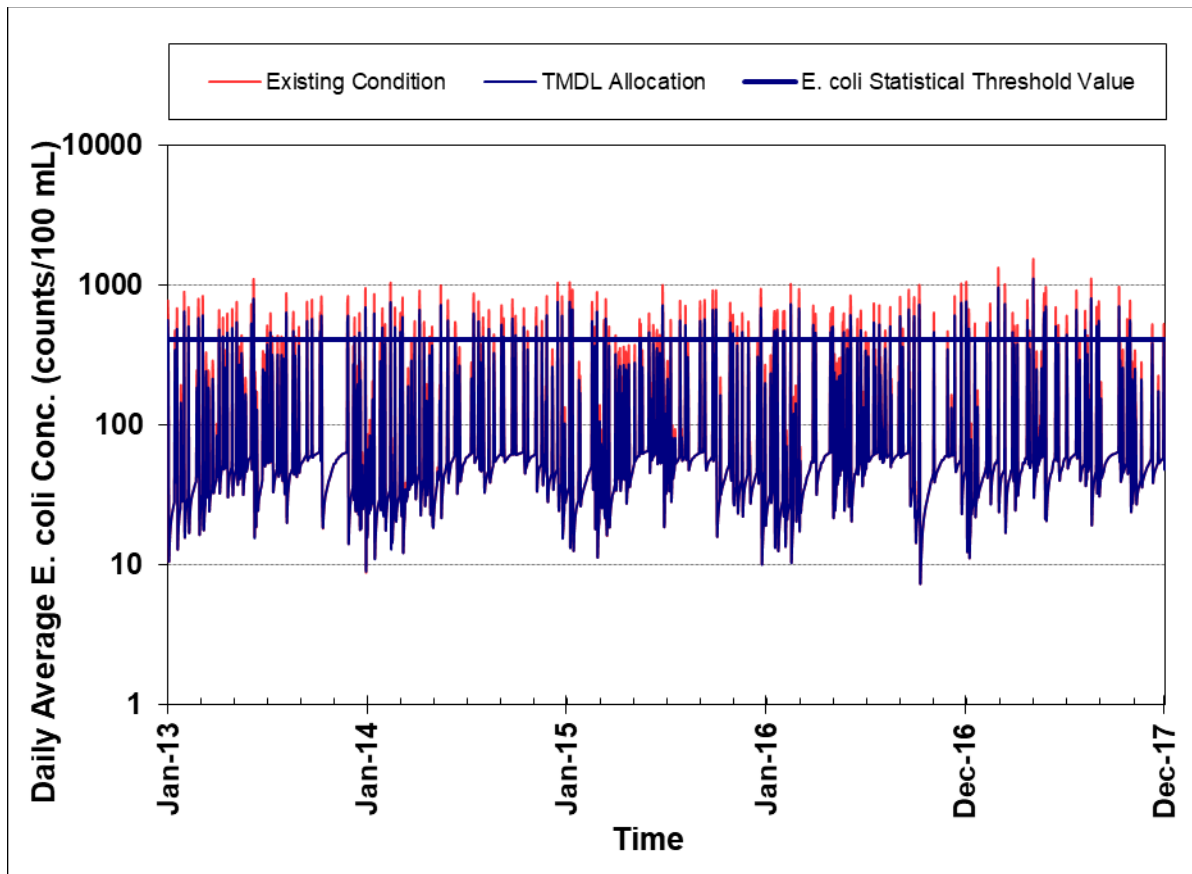
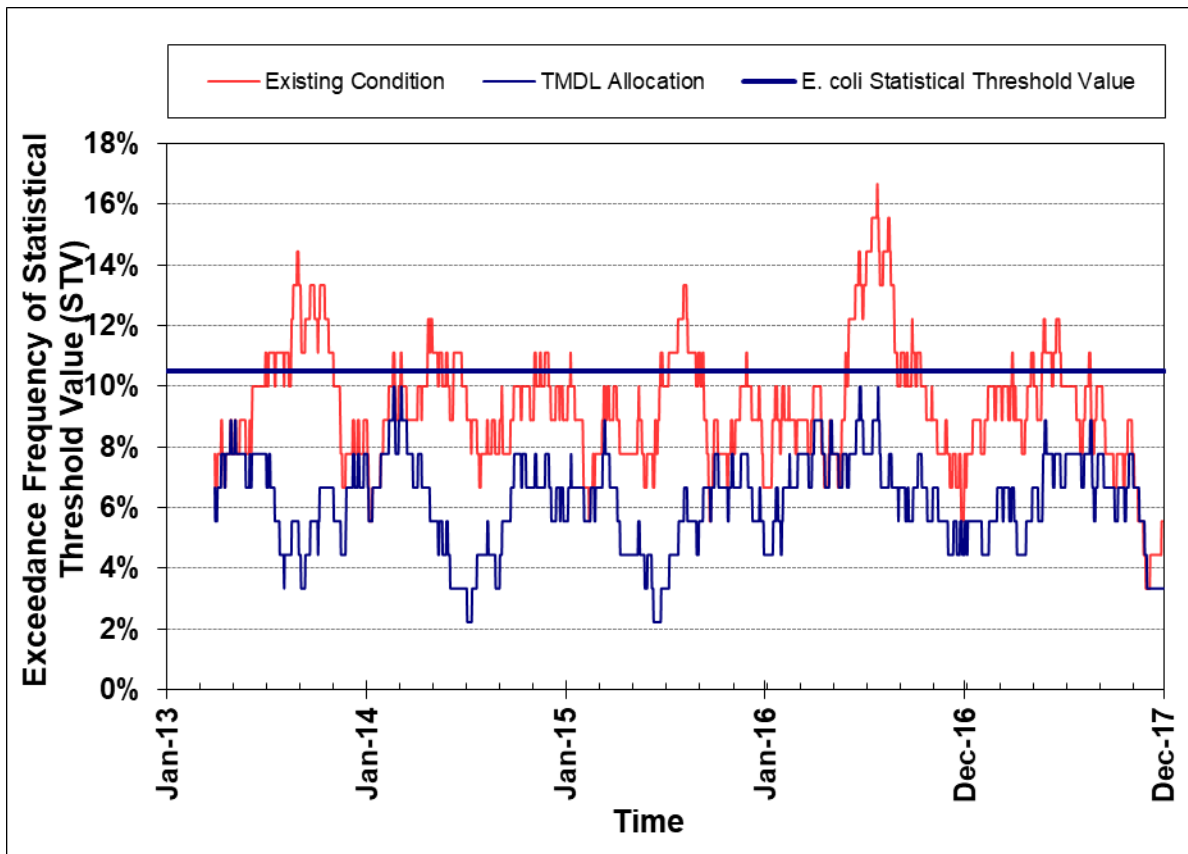


Figure 5-10. Dogwood Fork the rolling 90-day geometric mean *E. coli* concentrations under existing and TMDL conditions



*Figure 5-11. Dogwood Fork daily average E. coli concentrations under existing and TMDL conditions*



*Figure 5-12. Dogwood Fork exceedance frequency of the STV based on the rolling 90-day average E. coli concentrations under existing and TMDL conditions*

#### 5.5.5 Dorrell Creek (VAN-F21R\_DRL01A18)

The existing and allocated point and nonpoint source loads along with a TMDL summary for Dorrell Creek are presented in this section.

##### 5.5.5.1 Dorrell Creek Wasteload Allocation

There are no permitted point sources in the Dorrell Creek TMDL watershed; therefore, as outlined in DEQ recommendations (VADEQ, 2016a), two percent of the TMDL was set aside for future growth of developed land and residential human populations. The future growth value ( $5.75\text{E}+10$  counts per year *E. coli*) is assigned as the WLA in the Dorrell Creek TMDL watershed.

### 5.5.5.2 Dorrell Creek Load Allocation Plan and TMDL Summary

The scenarios modeled to determine the TMDL allocation for the Dorrell Creek TMDL watershed are listed in Table 5-17. No reductions in bacteria loads from forest and wetland were considered in any of the scenarios. According to the TMDL allocation scenario (number 5), the recommended reductions necessary for meeting the *E. coli* GM water quality criterion of 126 counts/100 ml and the statistical threshold value water quality criterion of 410 counts/100 ml for Dorrell Creek are:

- 100% reduction of the human sources (failed septic systems and straight pipes)
- 41% reduction of the direct livestock in-stream loading
- 21% reduction of bacteria loading from nonpoint sources (pasture, hay, cropland, and developed land)

*Table 5-17. Bacteria load allocation scenarios for Dorrell Creek TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml)*

Scenario	Failing Sewage Systems	Cattle Direct Deposition	Pasture	Hay	Cropland	Developed Land	Wildlife Direct Deposition	GM Exceedance Rate	STV Exceedance Rate
1	100	0	0	0	0	0	0	1	22
2	100	100	0	0	0	0	0	1	22
3	100	100	0	0	0	0	100	0	1
4	100	50	50	50	50	50	0	0	0
<b>5<sup>1</sup></b>	<b>100</b>	<b>41</b>	<b>21</b>	<b>21</b>	<b>21</b>	<b>21</b>	<b>0</b>	<b>0</b>	<b>0</b>

<sup>1</sup>Final TMDL Scenario

Table 5-18 shows the existing condition and TMDL allocation loads of *E. coli* and reductions using scenario 5 in the different land use categories within Dorrell Creek watershed.

*Table 5-18. Annual load existing conditions and allocations and percent reduction per land use category for Dorrell Creek TMDL Watershed*

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Forest and Wetland	4.44E+11	13.8	4.44E+11	0.0
Developed Land	2.67E+11	8.3	2.09E+11	21.6
Hay	1.24E+10	0.4	9.73E+09	21.6
Pasture	9.70E+11	30.2	7.60E+11	21.6
Cropland	3.32E+11	10.3	2.60E+11	21.6

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Cattle Direct Deposition	1.62E+10	0.5	9.54E+09	41.2
Wildlife Direct Deposition	1.13E+12	35.0	1.13E+12	0.0
Straight Pipes, Pit Privies, and Failing Septics	4.56E+10	1.4	0.00E+00	100.0
Point Source	0.00E+00	0.0	0.00E+00	0.0
Future Growth	0	0.0	5.75E+10	0.0
Total Loads	3.21E+12	100.0	2.88E+12	10.5

Table 5-19 shows the TMDL, which is the amount of *E. coli* that the stream can receive in a given year while still meeting the water quality standard. The average annual loads were estimated using a five-year (2013-2017) water quality simulation and taking into consideration the hydrologic and environmental processes involving the fate and transport of bacteria. The TMDL WLA reflects a future growth allocation for potential new or expanding dischargers in the future. Any permittees discharging bacteria will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The Load Allocation is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined at the downstream end of the impaired segment, the watershed outlet. This value may be different from nonpoint source loads provided in Table 5-18 because of factors such as bacteria die-off that occur between the point of deposition and the modeled watershed outlet.

*Table 5-19. Dorrell Creek TMDL (counts/year) for E. coli*

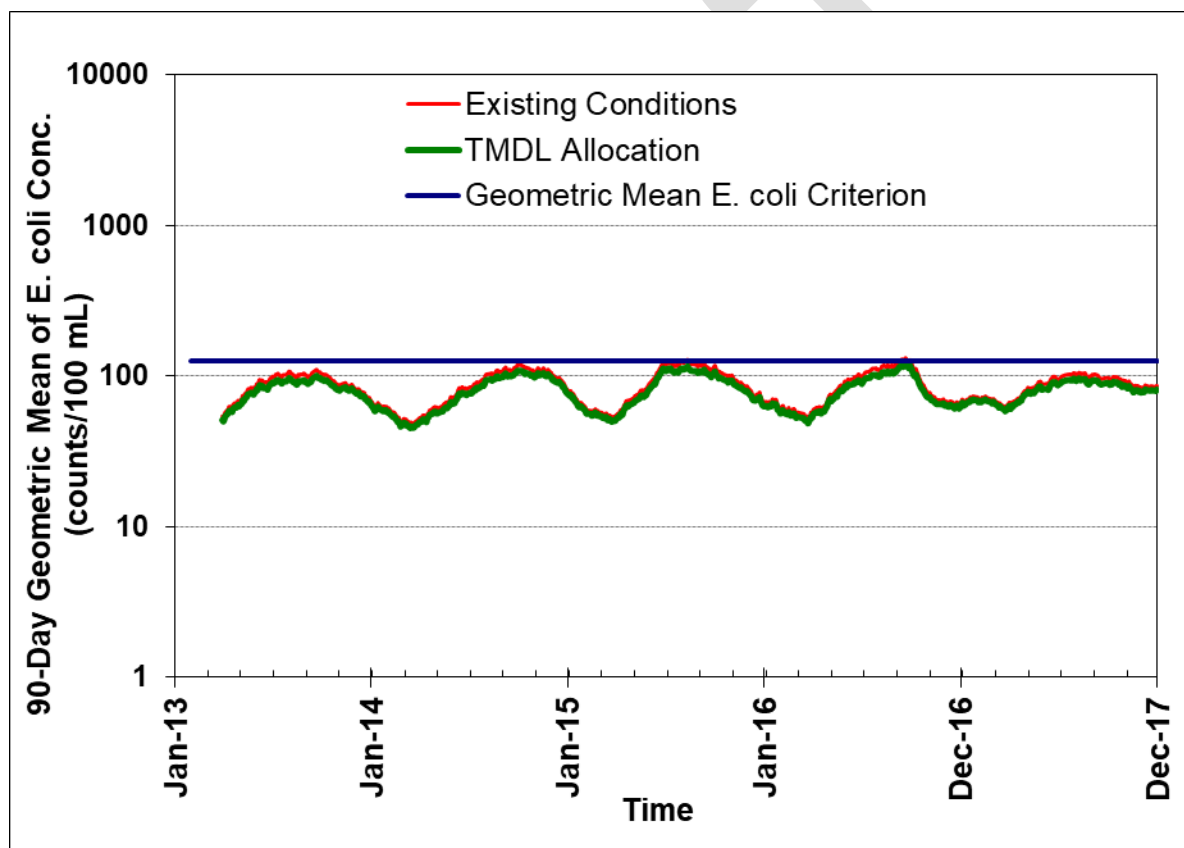
WLA	LA	MOS	TMDL
5.75E+10	2.82E+12	IMPLICIT	2.88E+12

The average annual *E. coli* loads were converted to daily loads using the approach discussed in section 5.6. The TMDL, expressed in daily loads, is given in Table 5-20.

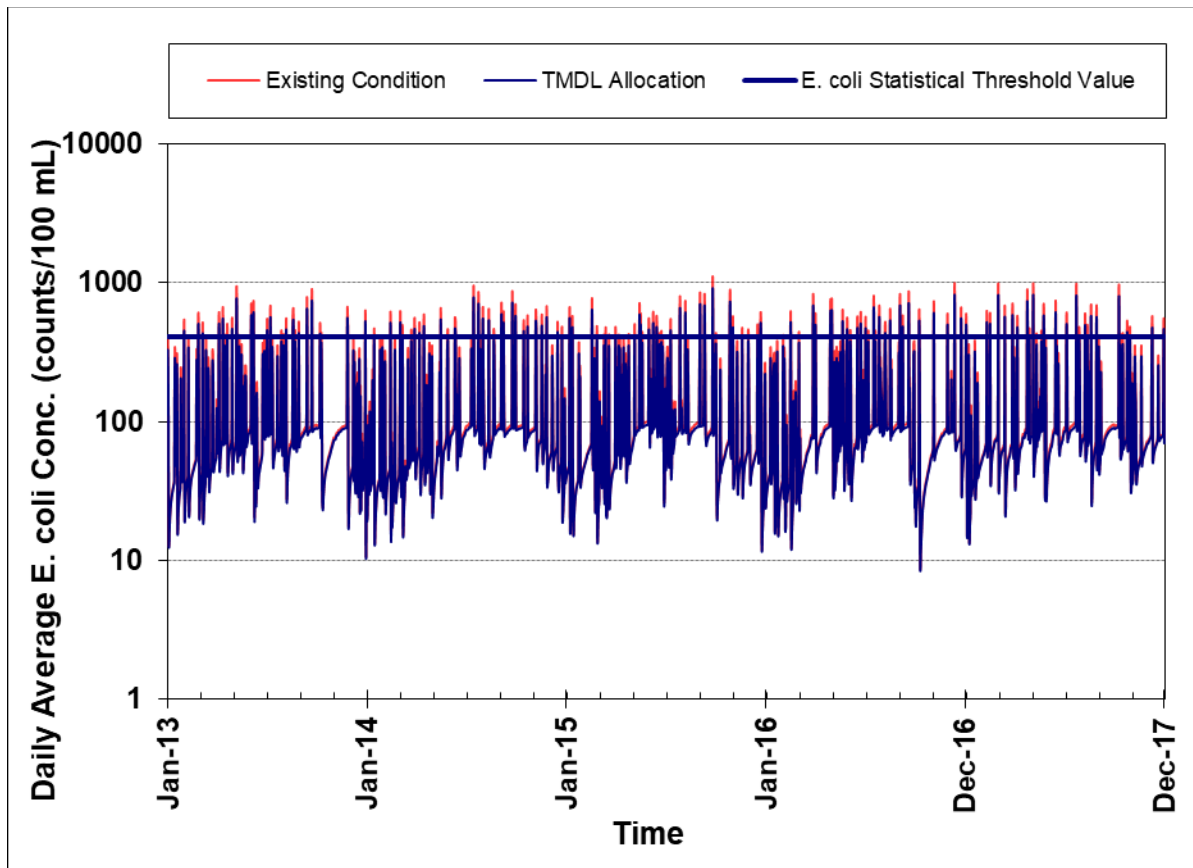
*Table 5-20. Dorrell Creek TMDL (counts/day) for E. coli*

WLA	LA	MOS	TMDL
1.58E+08	2.95E+10	IMPLICIT	2.97E+10

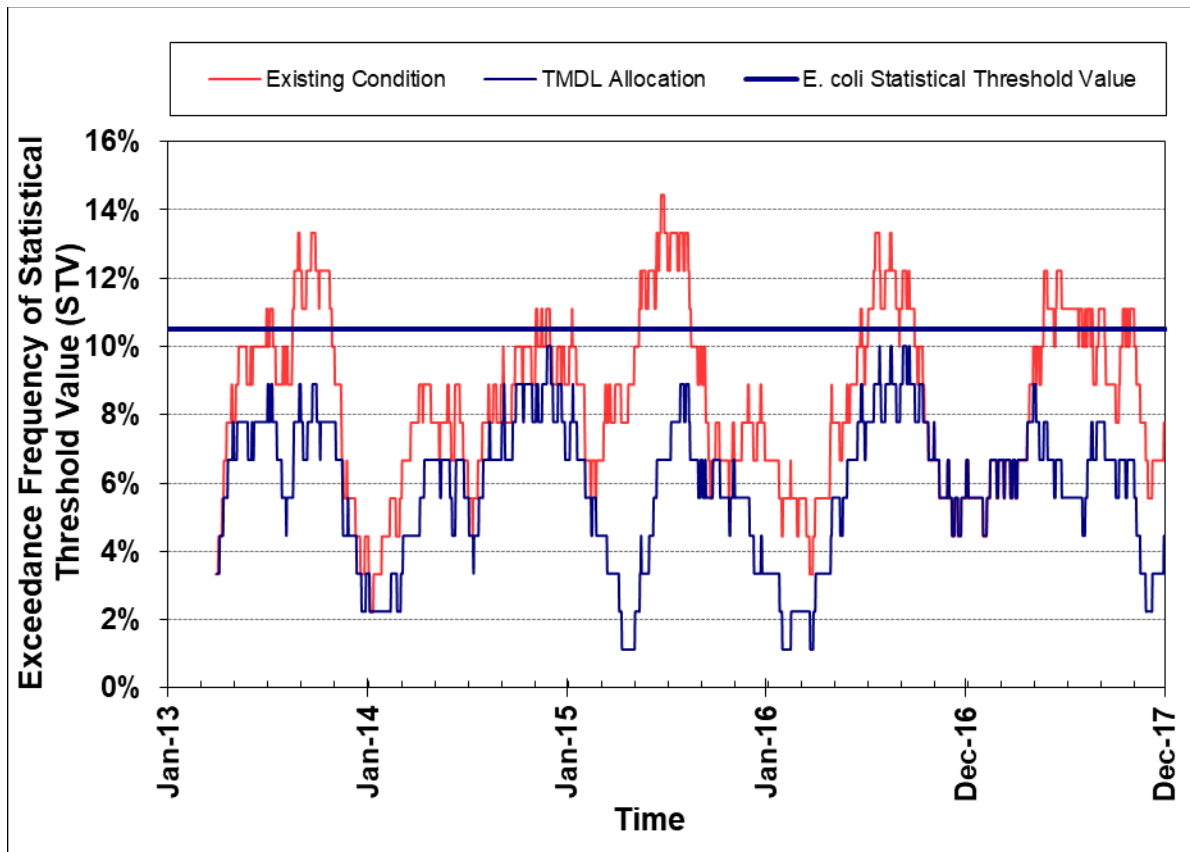
Figure 5-13 and Figure 5-14 show the 90-day geometric mean and daily average *E. coli* concentrations, respectively, under both the existing and the TMDL allocation conditions. Figure 5-15 shows the exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions. The figures also include the geometric mean and the statistical threshold value criteria as horizontal solid lines. The figures demonstrate that the developed TMDL ensures that, under the TMDL allocation conditions, both water quality criteria are met in the impaired segment of Dorrell Creek.



*Figure 5-13. Dorrell Creek the rolling 90-day geometric mean E. coli concentrations under existing and TMDL conditions*



*Figure 5-14. Dorrell Creek daily average E. coli concentrations under existing and TMDL conditions*



*Figure 5-15. Dorrell Creek exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions*

#### 5.5.6 Garnetts Creek (VAP-F23R\_GNT01A00)

The existing and allocated point and nonpoint source loads along with a TMDL summary for Garnetts Creek are presented in this section.

##### *5.5.6.1 Garnetts Creek Wasteload Allocation*

There are no permitted point sources in the Garnetts Creek TMDL watershed; therefore, as outlined in DEQ recommendations (VADEQ, 2016a), two percent of the TMDL was set aside for future growth of developed land and residential human populations. The future growth value (8.72E+10 counts per year *E. coli*) is assigned as the WLA in the Garnetts Creek TMDL watershed.

#### 5.5.6.2 Garnetts Creek Load Allocation Plan and TMDL Summary

The scenarios modeled to determine the TMDL allocation for the Garnetts Creek TMDL watershed are listed in Table 5-21. No reductions in bacteria loads from forest and wetland were considered in any of the scenarios. According to the TMDL allocation scenario (number 5), the recommended reductions necessary for meeting the *E. coli* GM water quality criterion of 126 counts/100 ml and the statistical threshold value water quality criterion of 410 counts/100 ml for Garnetts Creek are:

- 100% reduction of the human sources (failed septic systems and straight pipes)
- 41% reduction of the direct livestock in-stream loading
- 9% reduction of bacteria loading from nonpoint sources (pasture, hay, cropland, and developed land)

*Table 5-21. Bacteria load allocation scenarios for Garnetts Creek TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml)*

Scenario	Failing Sewage Systems	Cattle Direct Deposition	Pasture	Hay	Cropland	Developed Land	Wildlife Direct Deposition	GM Exceedance Rate	STV Exceedance Rate
1	100	0	0	0	0	0	0	12	18
2	100	100	0	0	0	0	0	0	0.2
3	100	100	0	0	0	0	100	0	0.2
4	100	50	50	50	50	50	0	0	0
<b>5<sup>1</sup></b>	<b>100</b>	<b>41</b>	<b>9</b>	<b>9</b>	<b>9</b>	<b>9</b>	<b>0</b>	<b>0</b>	<b>0</b>

<sup>1</sup>Final TMDL Scenario

Table 5-22 shows the existing condition *E. coli* loads, load allocations under scenario 5 and the reductions required for different land use categories and direct sources within Garnetts Creek watershed.

*Table 5-22. Annual load existing conditions and allocations and percent reduction per land use category for Garnetts Creek TMDL Watershed*

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Forest and Wetland	5.40E+10	1.2	5.40E+10	0.0
Developed Land	8.63E+11	18.9	7.78E+11	9.8
Hay	2.27E+10	0.5	2.04E+10	9.8

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Pasture	8.29E+11	18.2	7.47E+11	9.8
Cropland	1.09E+12	23.9	9.82E+11	9.8
Cattle Direct Deposition	3.18E+10	0.7	1.87E+10	41.2
Wildlife Direct Deposition	1.67E+12	36.6	1.67E+12	0.0
Straight Pipes, Pit Privies, and Failing Septics	0.00E+00	0.0	0.00E+00	100.0
Point Source	0.00E+00	0.0	0.00E+00	0.0
Future Growth	-	-	8.72E+10	-
Total Loads	4.56E+12	100.0	4.36E+12	4.4

Table 5-23 shows the TMDL, which is the amount of *E. coli* that the stream can receive in a given year while still meeting the water quality standard. The average annual loads were estimated using a five-year (2013-2017) water quality simulation and taking into consideration the hydrologic and environmental processes involving the fate and transport of bacteria. The TMDL WLA reflects a future growth allocation for potential new or expanding dischargers in the future. Any permittees discharging bacteria will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The Load Allocation is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined at the downstream end of the impaired segment, the watershed outlet. This value may be different from nonpoint source loads provided in Table 5-22 because of factors such as bacteria die-off that occur between the point of deposition and the modeled watershed outlet.

*Table 5-23. Garnetts Creek TMDL (counts/year) for E. coli*

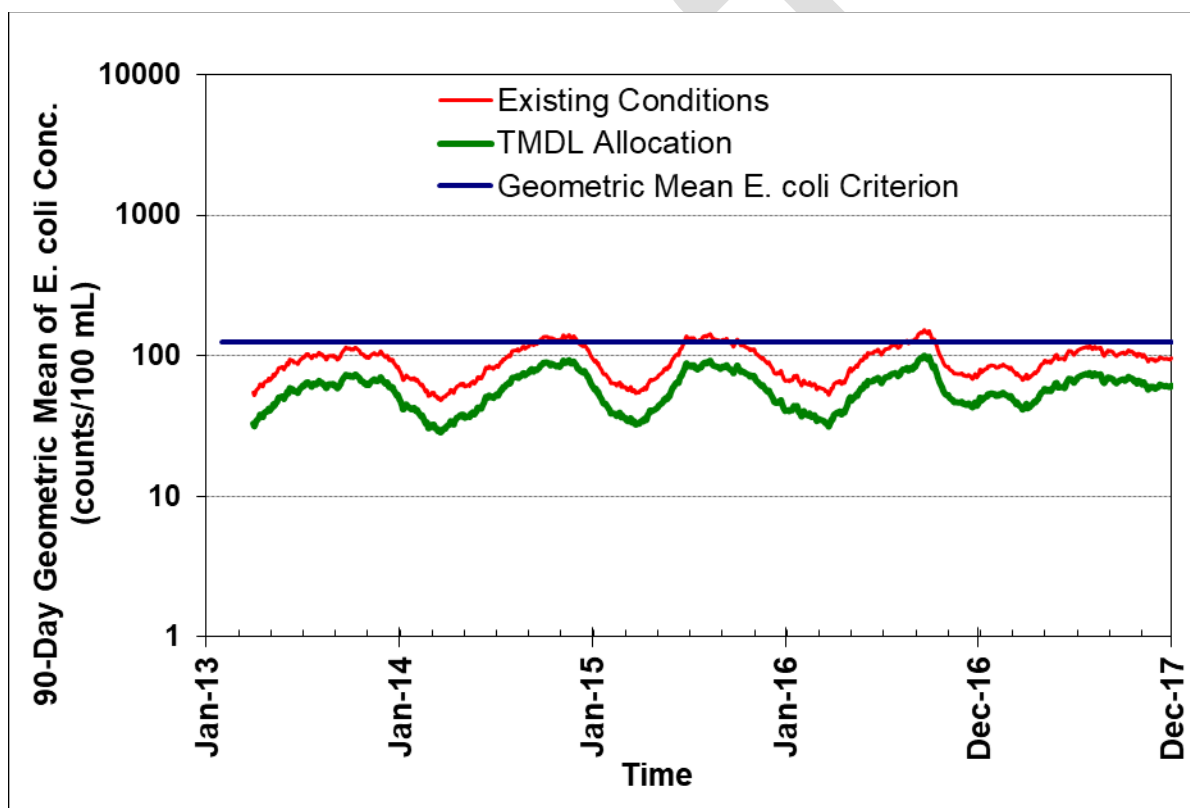
WLA	LA	MOS	TMDL
8.72E+10	4.27E+12	IMPLICIT	4.36E+12

The average annual *E. coli* loads were converted to daily loads using the approach discussed in section 5.6. The TMDL, expressed in daily loads, is given in Table 5-24.

*Table 5-24. Garnetts Creek TMDL (counts/day) for E. coli*

WLA	LA	MOS	TMDL
2.39E+08	4.46E+10	IMPLICIT	4.48E+10

Figure 5-16 and Figure 5-17 show the 90-day geometric mean and daily average *E. coli* concentrations, respectively, under both the existing and the TMDL allocation conditions. Figure 5-18 shows the exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions. The figures also include the geometric mean and the statistical threshold value criteria as horizontal solid lines. The figures demonstrate that the developed TMDL ensures that, under the TMDL allocation conditions, both water quality criteria are met in the impaired segment of Garnetts Creek.



*Figure 5-16. Garnetts Creek the rolling 90-day geometric mean *E. coli* concentrations under existing and TMDL conditions*

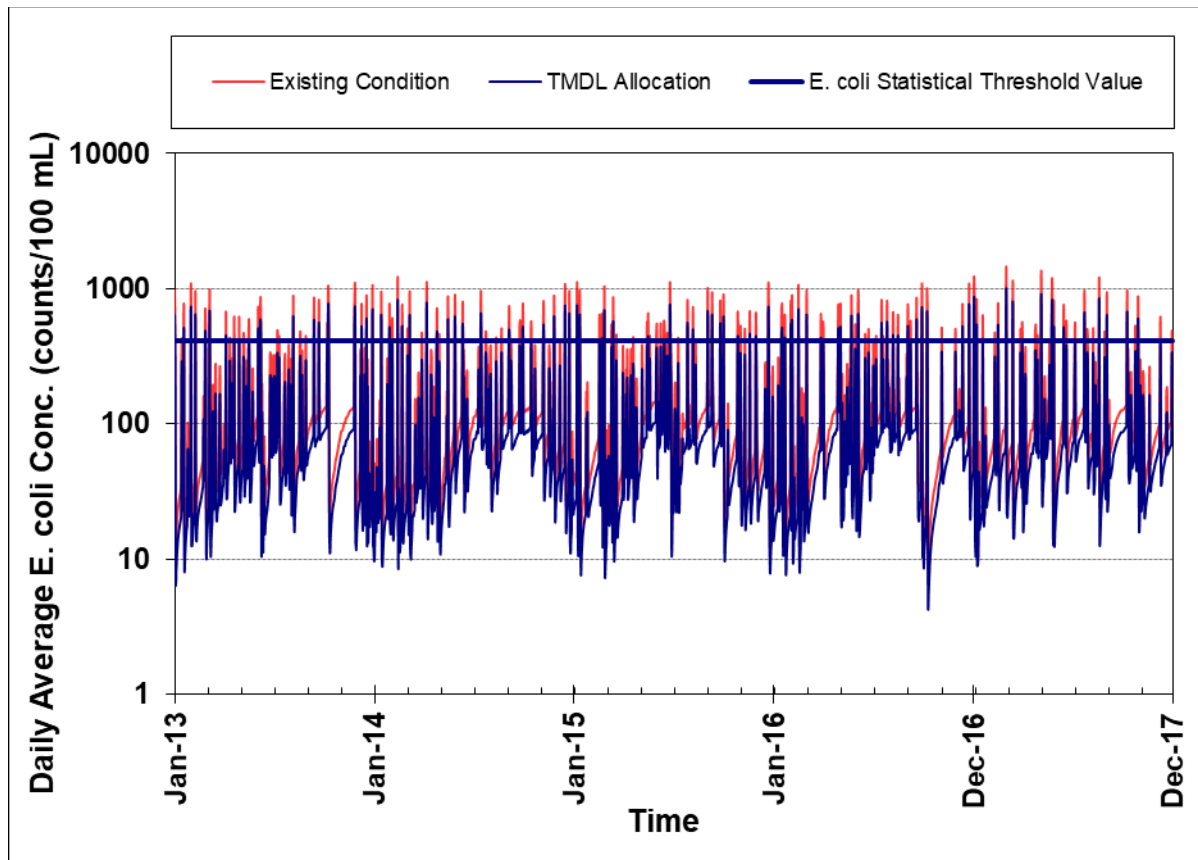
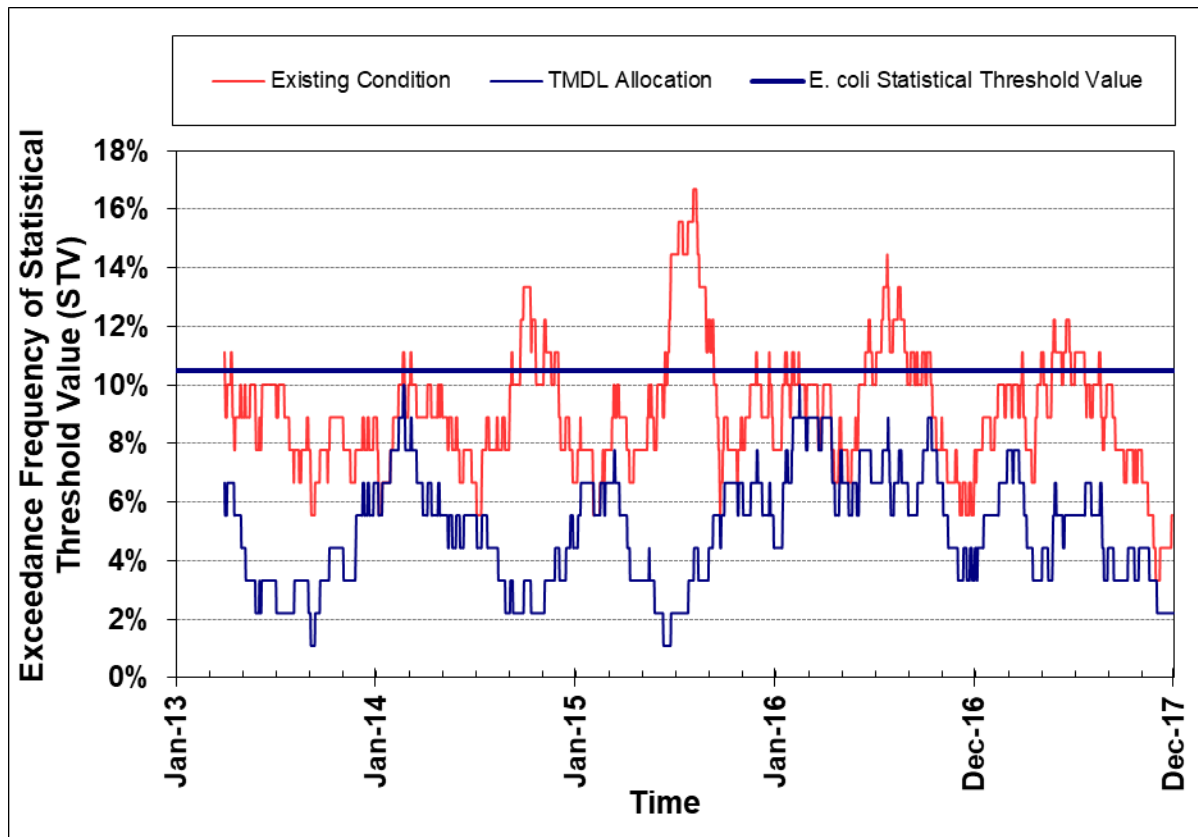


Figure 5-17. Garnetts Creek daily average *E. coli* concentrations under existing and TMDL conditions



*Figure 5-18. Garnetts Creek exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions*

#### 5.5.7 Gravel Run (VAN-F21R\_GVL01A18)

The existing and allocated point and nonpoint source loads along with a TMDL summary for Gravel Run are presented in this section.

##### *5.5.7.1 Gravel Run Wasteload Allocation*

There are no permitted point sources in the Gravel Run TMDL watershed; therefore, as outlined in DEQ recommendations (VADEQ, 2016a), two percent of the TMDL was set aside for future growth of developed land and residential human populations. The future growth value ( $1.10 \times 10^{11}$  counts per year *E. coli*) is assigned as the WLA in the Gravel Run TMDL watershed.

#### 5.5.7.2 Gravel Run Load Allocation Plan and TMDL Summary

The scenarios modeled to determine the TMDL allocation for the Gravel Run TMDL watershed are listed in Table 5-25. No reductions in bacteria loads from forest and wetland were considered in any of the scenarios. According to the TMDL allocation scenario (number 5), the recommended reductions necessary for meeting the *E. coli* GM water quality criterion of 126 counts/100 ml and the statistical threshold value water quality criterion of 410 counts/100 ml for Gravel Run are:

- 100% reduction of the human sources (failed septic systems and straight pipes)
- 26% reduction of the direct livestock in-stream loading
- 27% reduction of bacteria loading from nonpoint sources (pasture, hay, cropland, and developed land)

*Table 5-25. Bacteria load allocation scenarios for Gravel Run TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml)*

Scenario	Failing Sewage Systems	Cattle Direct Deposition	Pasture	Hay	Cropland	Developed Land	Wildlife Direct Deposition	GM Exceedance Rate	STV Exceedance Rate
1	100	0	0	0	0	0	0	0	0.3
2	100	100	0	0	0	0	0	0	0.3
3	100	100	0	0	0	0	100	0	0.3
4	100	50	50	50	50	50	0	0	0
<b>5<sup>1</sup></b>	<b>100</b>	<b>26</b>	<b>27</b>	<b>27</b>	<b>27</b>	<b>27</b>	<b>0</b>	<b>0</b>	<b>0</b>

<sup>1</sup>Final TMDL Scenario

Table 5-26 shows the existing condition *E. coli* loads, load allocations under scenario 5 and the reductions required for different land use categories and direct sources within Gravel Run watershed.

*Table 5-26. Annual load existing conditions and allocations and percent reduction per land use category for Gravel Run TMDL Watershed*

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Forest and Wetland	6.64E+11	9.9	6.64E+11	0.0
Developed Land	2.56E+11	3.8	1.86E+11	27.5
Hay	4.00E+10	0.6	2.90E+10	27.5

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Pasture	3.77E+12	56.2	2.73E+12	27.5
Cropland	6.15E+11	9.2	4.46E+11	27.5
Cattle Direct Deposition	3.14E+10	0.5	2.31E+10	26.5
Wildlife Direct Deposition	1.31E+12	19.5	1.31E+12	0.0
Straight Pipes, Pit Privies, and Failing Septics	2.25E+10	0.3	0.00E+00	100.0
Point Source	0.00E+00	0.0	0.00E+00	0.0
Future Growth	-	-	1.10E+11	-
Total Loads	6.71E+12	100.0	5.50E+12	18.0

Table 5-27 shows the TMDL, which is the amount of *E. coli* that the stream can receive in a given year while still meeting the water quality standard. The average annual loads were estimated using a five-year (2013-2017) water quality simulation and taking into consideration the hydrologic and environmental processes involving the fate and transport of bacteria. The TMDL WLA reflects a future growth allocation for potential new or expanding dischargers in the future. Any permittees discharging bacteria will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The Load Allocation is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined at the downstream end of the impaired segment, the watershed outlet. This value may be different from nonpoint source loads provided in Table 5-26 because of factors such as bacteria die-off that occur between the point of deposition and the modeled watershed outlet.

*Table 5-27. Gravel Run TMDL (counts/year) for E. coli*

WLA	LA	MOS	TMDL
1.10E+11	5.39E+12	IMPLICIT	5.50E+12

The average annual *E. coli* loads were converted to daily loads according to the approach outlined in the *USEPA OWOW 2007 Options for Expressing Daily Loads in TMDLs* (USEPA, 2007). Section 5.6 describes this approach in detail. The TMDL, expressed in daily loads, is given in Table 5-28.

Table 5-28. Gravel Run TMDL (counts/day) for *E. coli*

WLA	LA	MOS	TMDL
3.01E+08	5.59E+10	IMPLICIT	5.62E+10

Figure 5-19 and Figure 5-20 show the 90-day geometric mean and daily average *E. coli* concentrations, respectively, under both the existing and the TMDL allocation conditions. Figure 5-21 shows the exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions. The figures also include the geometric mean and the statistical threshold value criteria as horizontal solid lines. The figures demonstrate that the developed TMDL ensures that, under the TMDL allocation conditions, both water quality criteria are met in the impaired segment of Gravel Run.

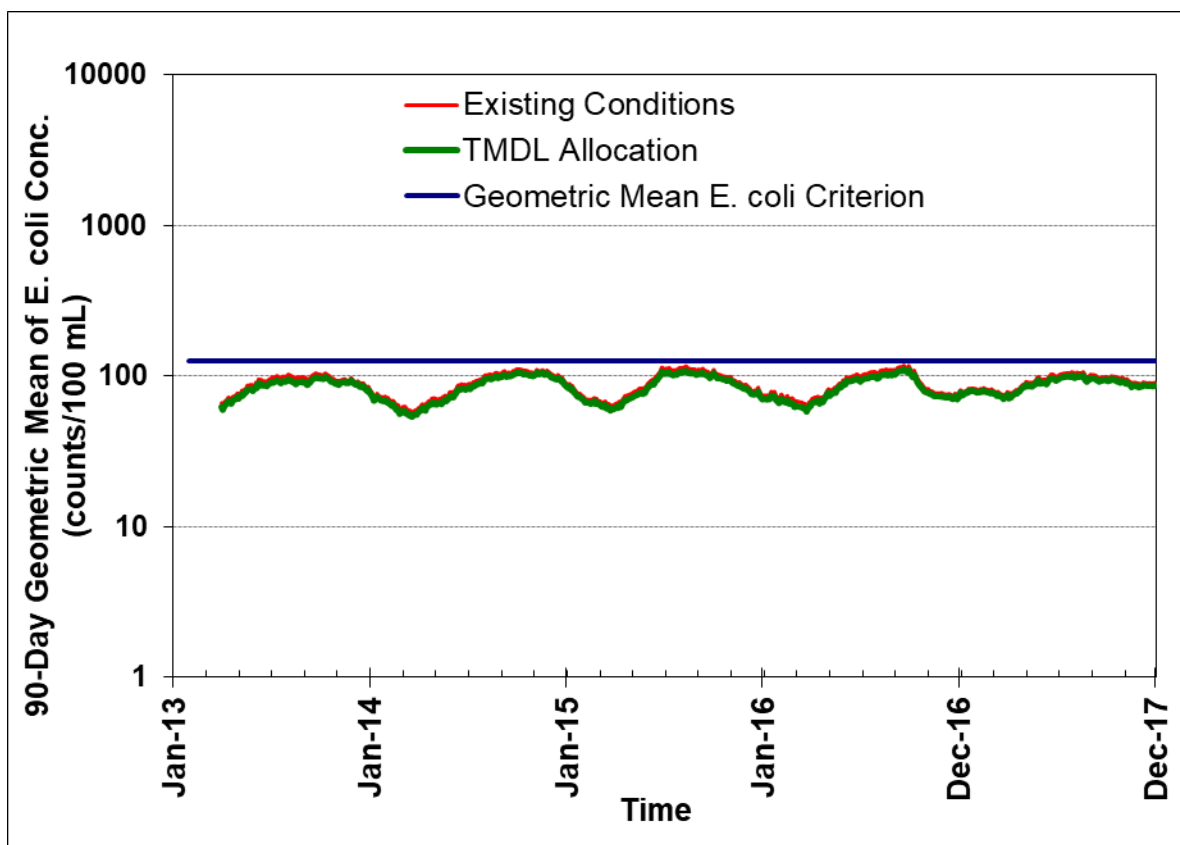
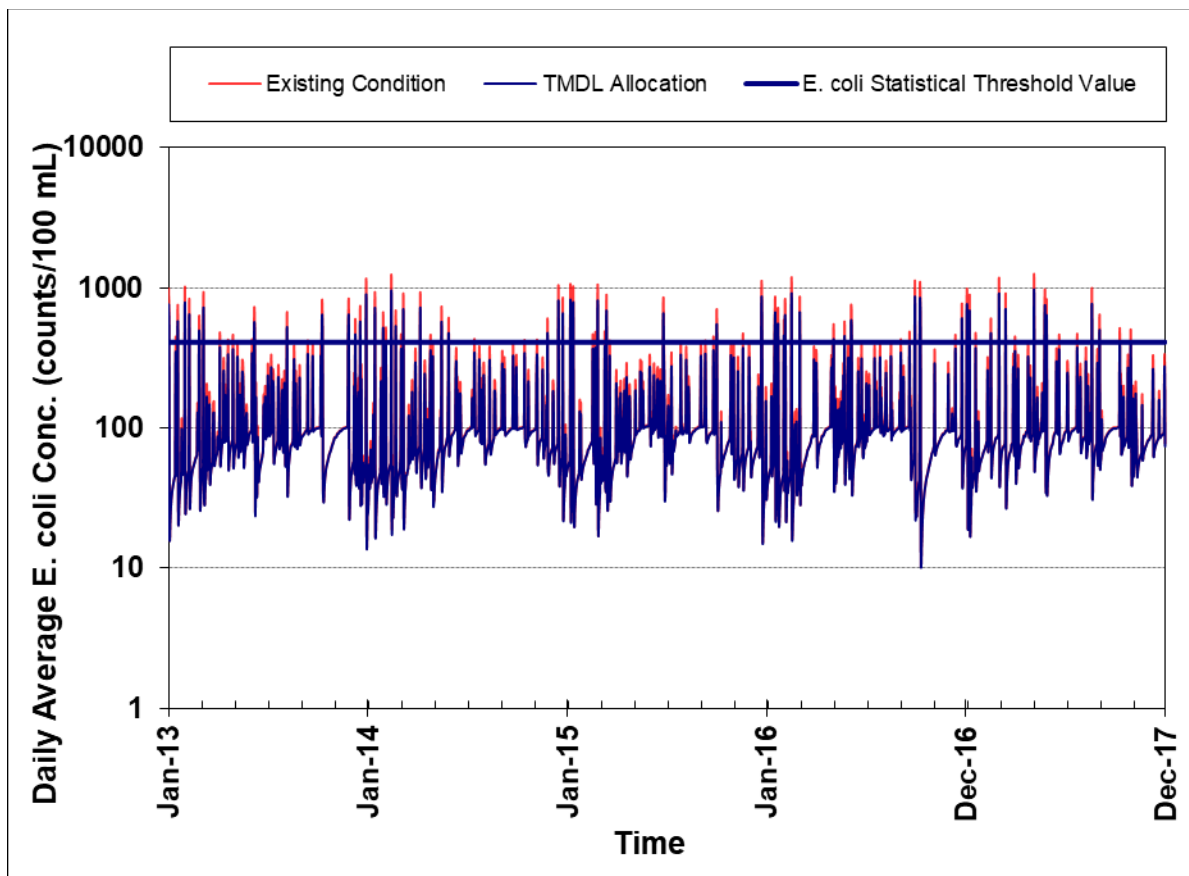


Figure 5-19. Gravel Run the rolling 90-day geometric mean *E. coli* concentrations under existing and TMDL conditions



*Figure 5-20. Gravel Run daily average E. coli concentrations under existing and TMDL conditions*

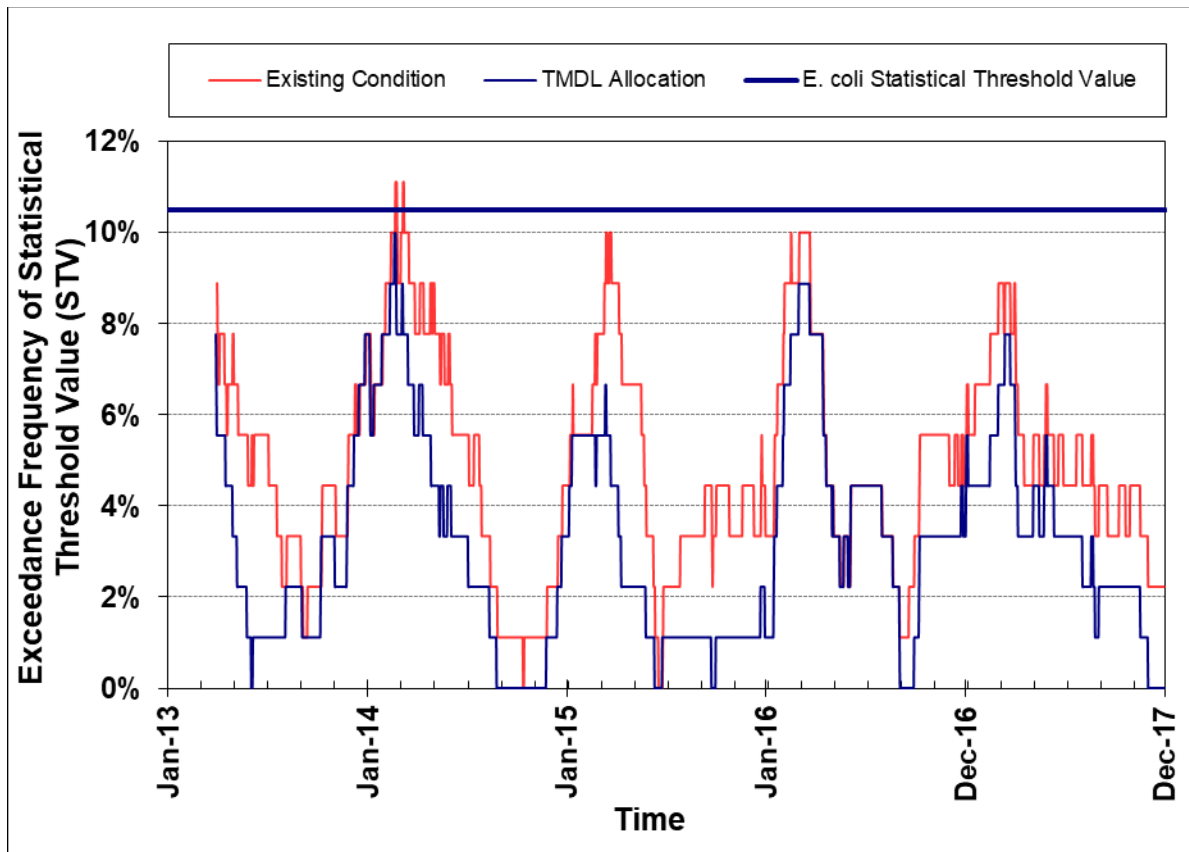


Figure 5-21. Gravel Run exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions

#### 5.5.8 Herring Creek (VAN-F21R\_HER01B02; VAN-F21R\_HER01A06)

The existing and allocated point and nonpoint source loads along with a TMDL summary for Herring Creek are presented in this section.

##### 5.5.8.1 Herring Creek Wasteload Allocation

One VPDES individual permitted facility exists in the Herring Creek TMDL watershed. For the allocation scenarios, the facility was assumed to discharge at design flow and have an effluent bacterial concentration monthly average limit equal to the existing *E. coli* geometric mean criterion of 126 counts/100 ml. Table 5-29 shows the design flow and allocated load of the discharger in Herring Creek TMDL watershed. The table also includes the *E. coli* bacteria load future growth allocation for Herring Creek. Following the DEQ recommendations (VADEQ,

2016a), two percent of the TMDL was set aside to account for future growth of developed land and residential human populations in the Herring Creek TMDL watershed.

*Table 5-29. Wasteload allocations for Herring Creek TMDL watershed*

Permit Number	Facility Name	Design Flow (MGD)	Allocated Load (counts/year)
VA0023329	DOC- Caroline Correctional Unit 2	0.037	6.44E+10
	Future Growth		5.66E+11
			TOTAL = 6.30E+11

#### 5.5.8.2 Herring Creek Load Allocation Plan and TMDL Summary

The scenarios modeled to determine the TMDL allocation for the Herring Creek TMDL watershed are listed in Table 5-30. No reductions in bacteria loads from forest and wetland were considered in any of the scenarios. According to the TMDL allocation scenario (number 5), the recommended reductions necessary for meeting the *E. coli* GM water quality criterion of 126 counts/100 ml and the statistical threshold value water quality criterion of 410 counts/100 ml for Herring Creek are:

- 100% reduction of the human sources (failed septic systems and straight pipes)
- 95% reduction of the direct livestock in-stream loading
- 11% reduction of bacteria loading from nonpoint sources (pasture, hay, cropland, and developed land)

*Table 5-30. Bacteria load allocation scenarios for Herring Creek TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml)*

Scenario	Failing Sewage Systems	Cattle Direct Deposition	Pasture	Hay	Cropland	Developed Land	Wildlife Direct Deposition	GM Exceedance Rate	STV Exceedance Rate
1	100	0	0	0	0	0	0	20	25
2	100	100	0	0	0	0	0	0.2	0
3	100	100	0	0	0	0	100	0	0
4	100	50	50	50	50	50	0	0	0
<b>5<sup>1</sup></b>	<b>100</b>	<b>95</b>	<b>11</b>	<b>11</b>	<b>11</b>	<b>11</b>	<b>0</b>	<b>0</b>	<b>0</b>

<sup>1</sup>Final TMDL Scenario

Table 5-31 shows the existing condition *E. coli* loads, load allocations under scenario 5 and the reductions required for different land use categories and direct sources within Herring Creek watershed.

*Table 5-31. Annual load existing conditions and allocations and percent reduction per land use category for Herring Creek TMDL Watershed*

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Forest and Wetland	4.96E+12	16.5	4.96E+12	0.0
Developed Land	2.65E+12	8.8	2.34E+12	11.8
Hay	2.39E+11	0.8	2.11E+11	11.8
Pasture	1.24E+13	41.1	1.09E+13	11.8
Cropland	3.87E+12	12.9	3.41E+12	11.8
Cattle Direct Deposition	2.05E+10	0.1	1.01E+09	95.1
Wildlife Direct Deposition	5.83E+12	19.4	5.83E+12	0.0
Straight Pipes, Pit Privies, and Failing Septics	5.59E+10	0.2	0.00E+00	100.0
Point Source	6.44E+10	0.2	6.44E+10	0.0
Future Growth	-	-	5.66E+11	-
Total Loads	3.01E+13	100.0	2.83E+13	5.7

The TMDL, which is the amount of *E. coli* that the stream can receive in a given year while still meeting the water quality standard, is presented in Table 5-32. The average annual loads were estimated using a five-year (2013-2017) water quality simulation and taking into consideration the hydrologic and environmental processes involving the fate and transport of bacteria. The TMDL WLA reflects a future growth allocation for potential new or expanding dischargers in the future. Any permittees discharging bacteria will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The Load Allocation is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined at the downstream end of the impaired segment, the watershed outlet. This value may be different from Table 5-31 providing nonpoint source loads because of factors such as bacteria die-off that occur between the point of deposition and the modeled watershed outlet.

Table 5-32. Herring Creek TMDL (counts/year) for *E. coli*

WLA	LA	MOS	TMDL
6.30E+11	2.77E+13	IMPLICIT	2.83E+13

The average annual *E. coli* loads were converted to daily loads using the approach discussed in section 5.6. The TMDL, expressed in daily loads, is given in Table 5-33.

Table 5-33. Herring Creek TMDL (counts/day) for *E. coli*

WLA	LA	MOS	TMDL
2.26E+09	2.87E+11	IMPLICIT	2.89E+11

Figure 5-22 and Figure 5-23 show the 90-day geometric mean and daily average *E. coli* concentrations, respectively, under both the existing and the TMDL allocation conditions. Figure 5-24 shows the exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions. The figures also include the geometric mean and the statistical threshold value criteria as horizontal solid lines. The figures demonstrate that the developed TMDL ensures that, under the TMDL allocation conditions, both water quality criteria are met in the impaired segment of Herring Creek.

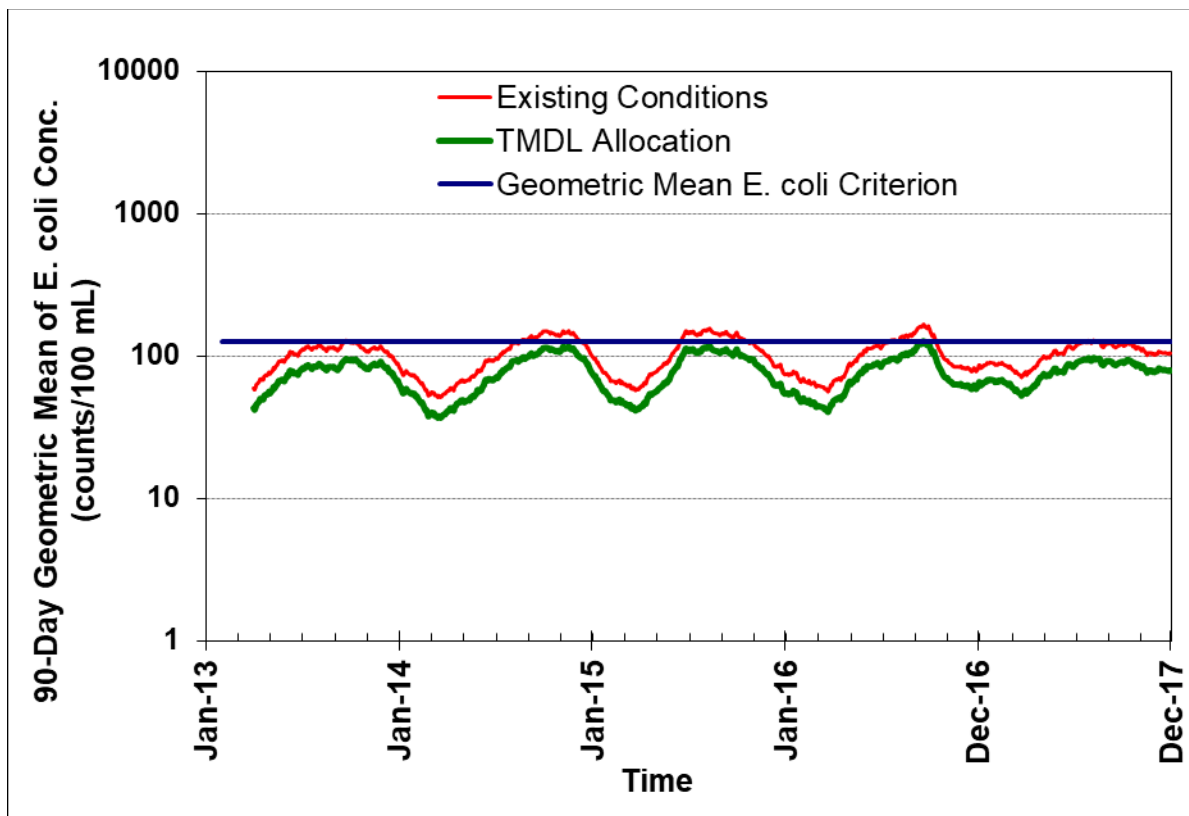
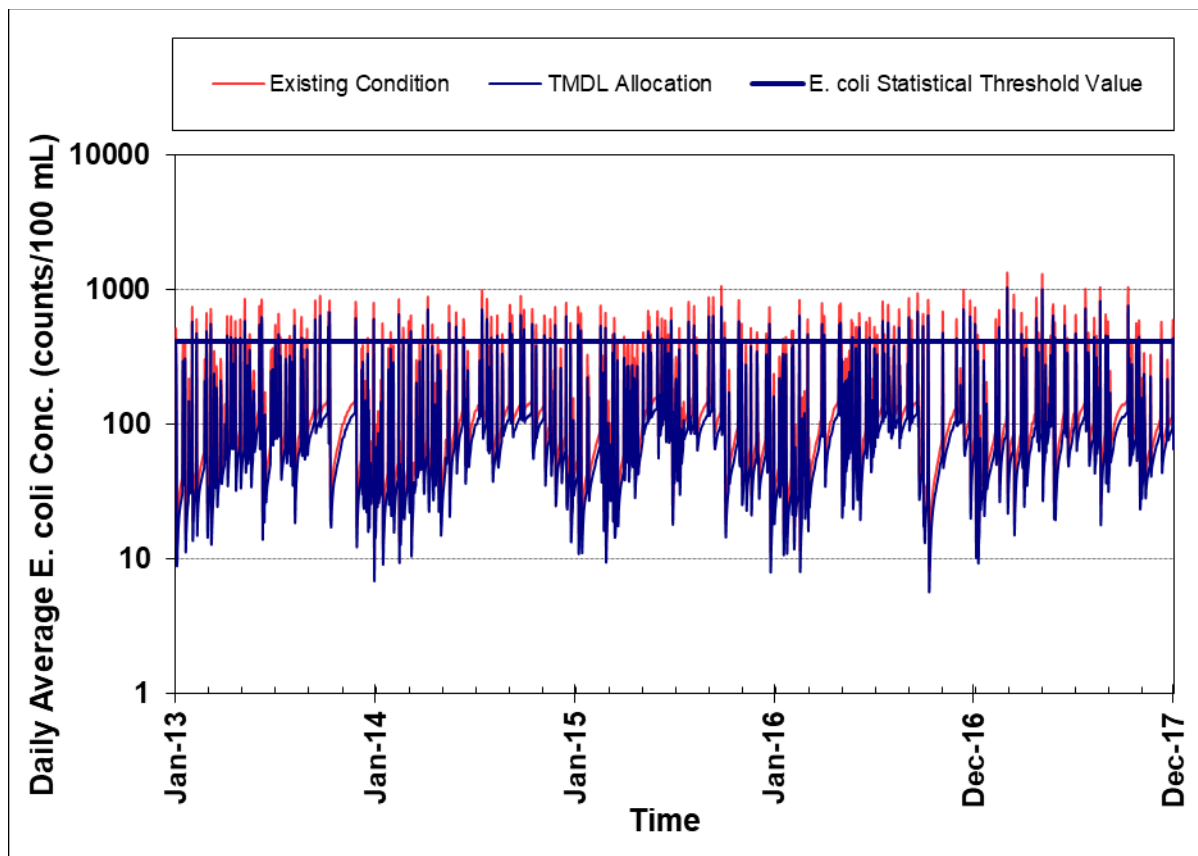
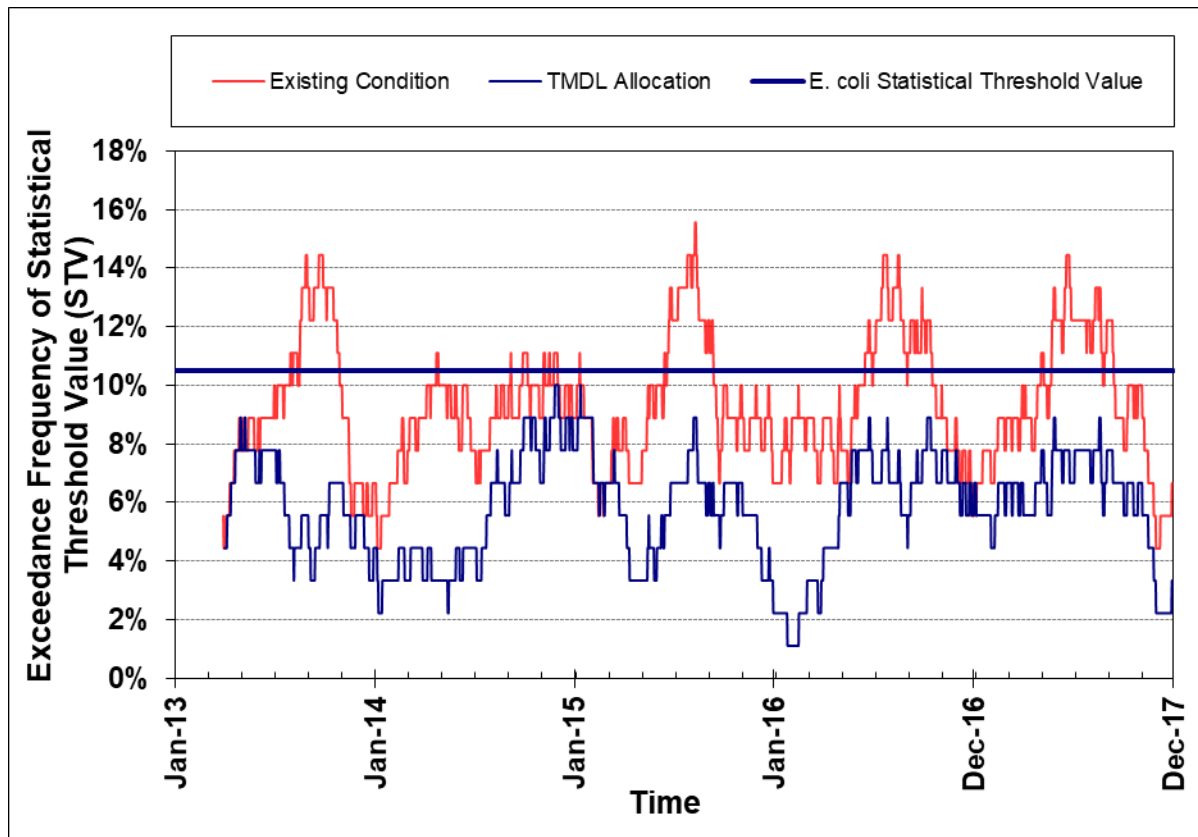


Figure 5-22. Herring Creek the rolling 90-day geometric mean *E. coli* concentrations under existing and TMDL conditions



*Figure 5-23. Herring Creek daily average E. coli concentrations under existing and TMDL conditions*



*Figure 5-24. Herring Creek exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions*

#### 5.5.9 Market Swamp (VAP-F23R\_MKT01B00)

The existing and allocated point and nonpoint source loads along with a TMDL summary for Market Swamp are presented in this section.

##### *5.5.9.1 Market Swamp Wasteload Allocation*

There are no permitted point sources in the Market Swamp TMDL watershed; therefore, as outlined in DEQ recommendations (VADEQ, 2016a), two percent of the TMDL was set aside for future growth of developed land and residential human populations. The future growth value ( $1.10 \times 10^{11}$  counts per year *E. coli*) is assigned as the WLA in the Market Swamp TMDL watershed.

### 5.5.9.2 Market Swamp Load Allocation Plan and TMDL Summary

The scenarios modeled to determine the TMDL allocation for the Market Swamp TMDL watershed are listed in Table 5-34. No reductions in bacteria loads from forest and wetland were considered in any of the scenarios. According to the TMDL allocation scenario (number 5), the recommended reductions necessary for meeting the *E. coli* GM water quality criterion of 126 counts/100 ml and the statistical threshold value water quality criterion of 410 counts/100 ml for Market Swamp are:

- 100% reduction of the human sources (failed septic systems and straight pipes)
- 41% reduction of the direct livestock in-stream loading
- 58% reduction of bacteria loading from nonpoint sources (pasture, hay, cropland, and developed land)

*Table 5-34. Bacteria load allocation scenarios for Market Swamp TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml)*

Scenario	Failing Sewage Systems	Cattle Direct Deposition	Pasture	Hay	Cropland	Developed Land	Wildlife Direct Deposition	GM Exceedance Rate	STV Exceedance Rate
1	100	0	0	0	0	0	0	1	14
2	100	100	0	0	0	0	0	1	14
3	100	100	0	0	0	0	100	0	4
4	100	50	50	50	50	50	0	0	0.3
<b>5<sup>1</sup></b>	<b>100</b>	<b>41</b>	<b>58</b>	<b>58</b>	<b>58</b>	<b>58</b>	<b>0</b>	<b>0</b>	<b>0</b>

<sup>1</sup>Final TMDL Scenario

Table 5-35 shows the existing condition *E. coli* loads, load allocations under scenario 5 and the reductions required for different land use categories and direct sources within Market Swamp watershed.

*Table 5-35. Annual load existing conditions and allocations and percent reduction per land use category for Market Swamp TMDL Watershed*

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Forest and Wetland	4.02E+12	65.5	4.02E+12	0.0
Developed Land	3.15E+11	5.1	1.30E+11	58.8
Hay	9.03E+10	1.5	3.72E+10	58.8

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Pasture	6.78E+11	11.0	2.79E+11	58.8
Cropland	1.92E+11	3.1	7.91E+10	58.8
Cattle Direct Deposition	3.30E+10	0.5	1.94E+10	41.2
Wildlife Direct Deposition	8.15E+11	13.3	8.15E+11	0.0
Straight Pipes, Pit Privies, and Failing Septics	0.00E+00	0.0	0.00E+00	100.0
Point Source	0.00E+00	0.0	0.00E+00	0.0
Future Growth	-	-	1.10E+11	-
Total Loads	6.15E+12	100.0	5.49E+12	10.6

Table 5-36 shows the TMDL, which is the amount of *E. coli* that the stream can receive in a given year while still meeting the water quality standard. The average annual loads were estimated using a five-year (2013-2017) water quality simulation and taking into consideration the hydrologic and environmental processes involving the fate and transport of bacteria. The TMDL WLA reflects a future growth allocation for potential new or expanding dischargers in the future. Any permittees discharging bacteria will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The Load Allocation is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined at the downstream end of the impaired segment, the watershed outlet. This value may be different from nonpoint source loads provided Table 5-35 because of factors such as bacteria die-off that occur between the point of deposition and the modeled watershed outlet.

*Table 5-36. Market Swamp TMDL (counts/year) for E. coli*

WLA	LA	MOS	TMDL
1.10E+11	5.38E+12	IMPLICIT	5.49E+12

The average annual *E. coli* loads were converted to daily loads using the approach discussed in section 5.6. The TMDL, expressed in daily loads, is given in Table 5-37.

*Table 5-37. Market Swamp TMDL (counts/day) for E. coli*

WLA	LA	MOS	TMDL
3.01E+08	5.64E+10	IMPLICIT	5.67E+10

Figure 5-25 and Figure 5-26 show the 90-day geometric mean and daily average *E. coli* concentrations, respectively, under both the existing and the TMDL allocation conditions. Figure 5-27 shows the exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions. The figures also include the geometric mean and the statistical threshold value criteria as horizontal solid lines. The figures demonstrate that the developed TMDL ensures that, under the TMDL allocation conditions, both water quality criteria are met in the impaired segment of Market Swamp.

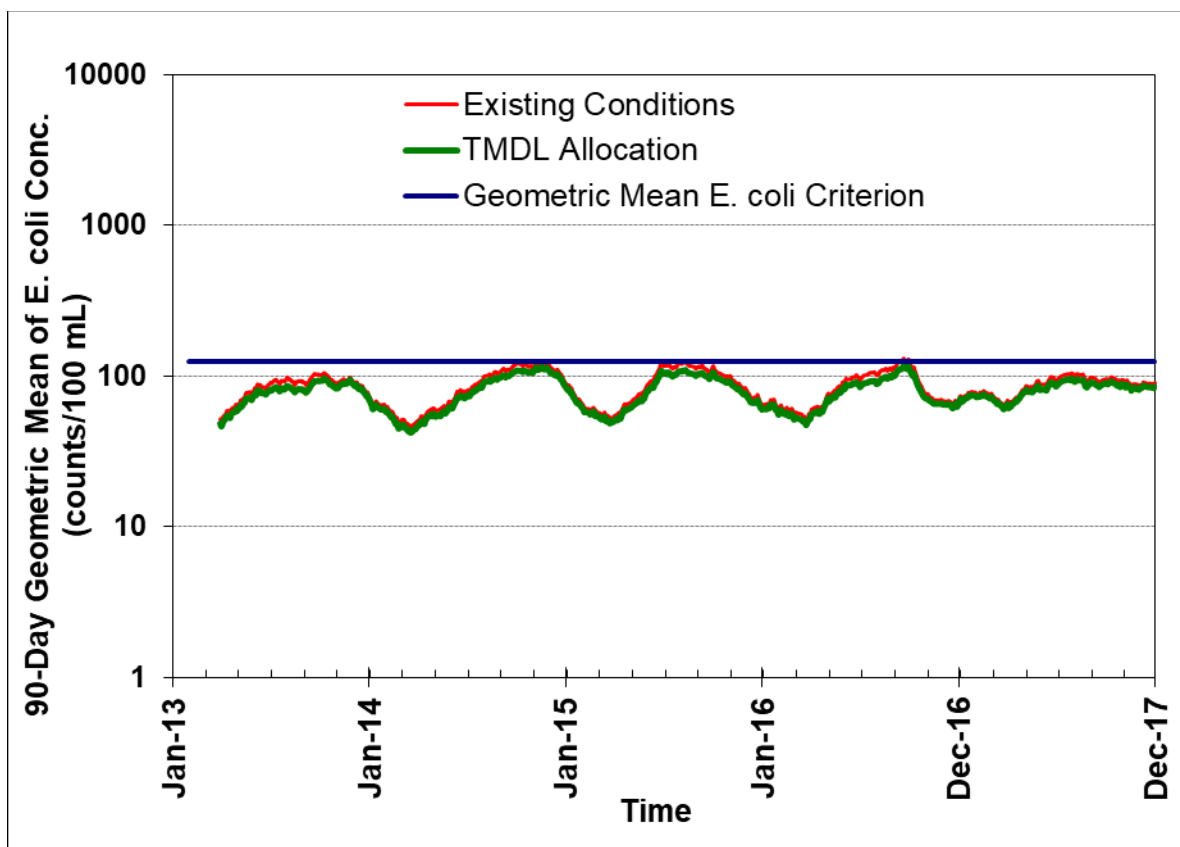


Figure 5-25. Market Swamp the rolling 90-day geometric mean *E. coli* concentrations under existing and TMDL conditions

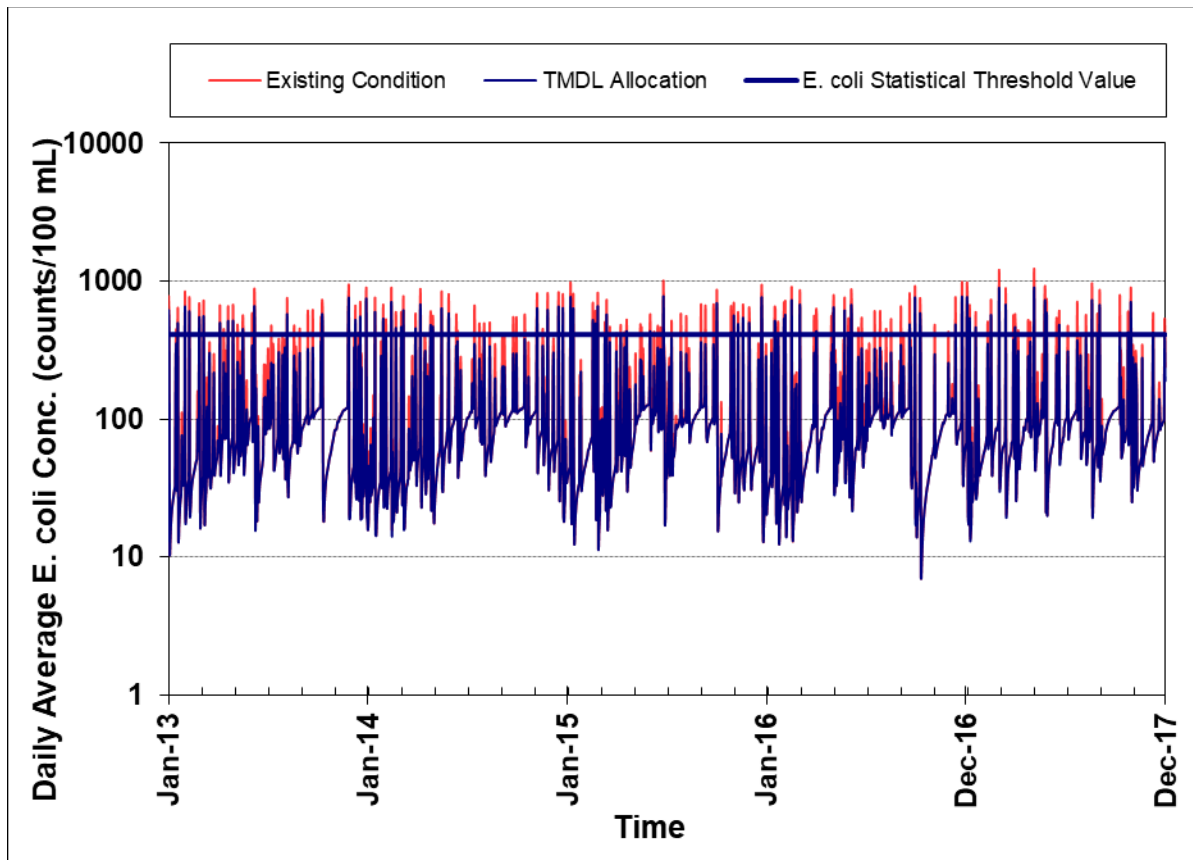
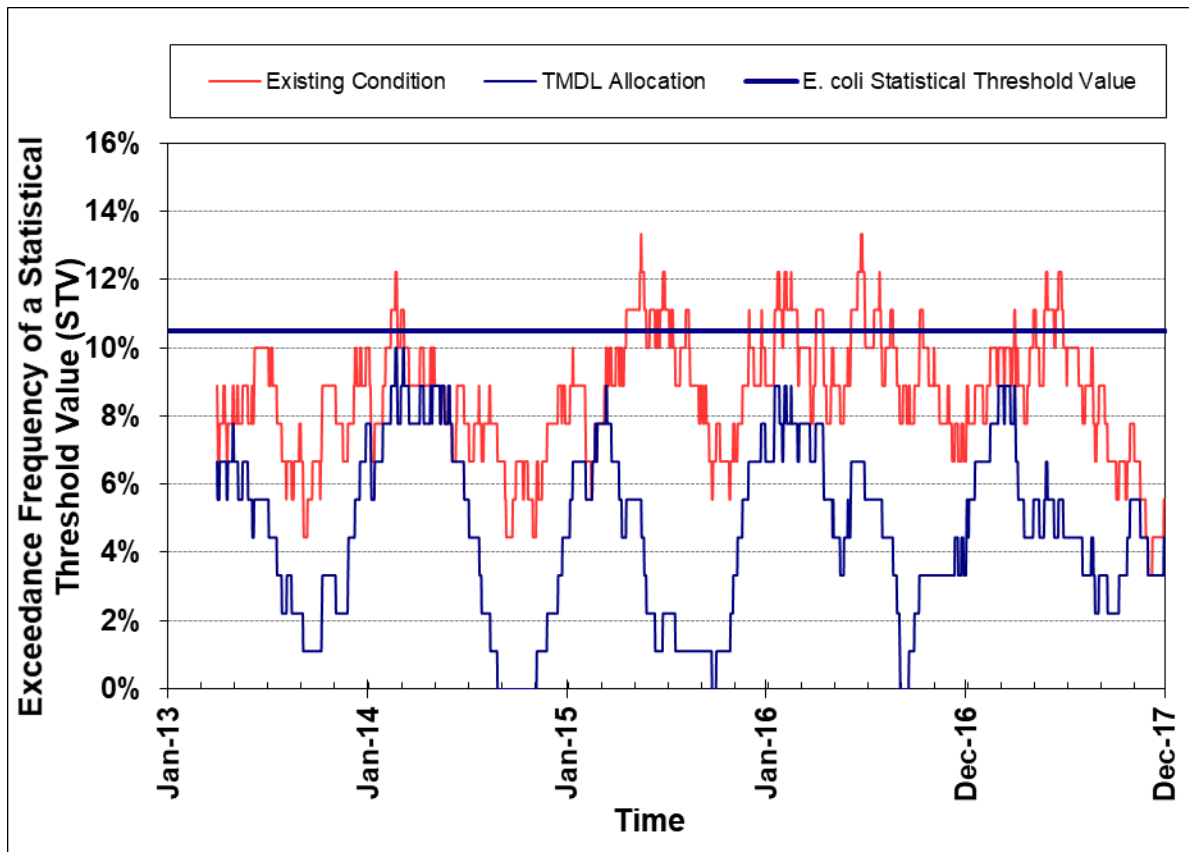


Figure 5-26. Market Swamp daily average *E. coli* concentrations under existing and TMDL conditions



*Figure 5-27. Market Swamp exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions*

#### 5.5.10 Mattaponi River (non-tidal) (VAN-F21R\_MPN01C02; VAN-F21R\_MPN01B02)

The existing and allocated point and nonpoint source loads along with a TMDL summary for Mattaponi River are presented in this section.

##### *5.5.10.1 Mattaponi River Wasteload Allocation*

There are no permitted point sources in the Mattaponi River (non-tidal) TMDL watershed; therefore, as outlined in DEQ recommendations (VADEQ, 2016a), two percent of the TMDL was set aside for future growth of developed land and residential human populations. The future growth value ( $1.10\text{E}+12$  counts per year *E. coli*) is assigned as the WLA in the Mattaponi River (non-tidal) TMDL watershed.

#### 5.5.10.2 Mattaponi River Load Allocation Plan and TMDL Summary

The scenarios modeled to determine the TMDL allocation for the Mattaponi River TMDL watershed are listed in Table 5-38. No reductions in bacteria loads from forest and wetland were considered in any of the scenarios. According to the TMDL allocation scenario (number 5), the recommended reductions necessary for meeting the *E. coli* GM water quality criterion of 126 counts/100 ml and the statistical threshold value water quality criterion of 410 counts/100 ml for Mattaponi River are:

- 100% reduction of the human sources (failed septic systems and straight pipes)
- 85% reduction of the direct livestock in-stream loading
- 80% reduction of bacteria loading from nonpoint sources (pasture, hay, cropland, and developed land)

*Table 5-38. Bacteria load allocation scenarios for Mattaponi River TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml)*

Scenario	Failing Sewage Systems	Cattle Direct Deposition	Pasture	Hay	Cropland	Developed Land	Wildlife Direct Deposition	GM Exceedance Rate	STV Exceedance Rate
1	100	0	0	0	0	0	0	0.7	1
2	100	100	0	0	0	0	0	0.1	0.7
3	100	100	0	0	0	0	100	0	0.7
4	100	50	50	50	50	50	0	0	0.3
<b>5<sup>1</sup></b>	<b>100</b>	<b>85</b>	<b>80</b>	<b>80</b>	<b>80</b>	<b>80</b>	<b>0</b>	<b>0</b>	<b>0</b>

<sup>1</sup>Final TMDL Scenario

Table 5-39 shows the existing condition *E. coli* loads, load allocations under scenario 5 and the reductions required for different land use categories and direct sources within the lower Mattaponi River watershed.

*Table 5-39. Annual load existing conditions and allocations and percent reduction per land use category for Mattaponi River TMDL Watershed*

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Forest and Wetland	2.31E+12	3.1	2.31E+12	0.0
Developed Land	3.27E+12	4.4	6.41E+11	80.4
Hay	8.13E+10	0.1	1.59E+10	80.4

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Pasture	2.05E+13	27.5	4.01E+12	80.4
Cropland	7.62E+12	10.2	1.49E+12	80.4
Cattle Direct Deposition	4.58E+10	0.1	6.73E+09	85.3
Wildlife Direct Deposition	4.06E+13	54.5	4.06E+13	0.0
Straight Pipes, Pit Privies, and Failing Septics	1.38E+11	0.2	0.00E+00	100.0
Point Source	0.00E+00	0.0	0.00E+00	0.0
Future Growth	-	-	1.00E+12	-
Total Loads	7.45E+13	100.0	5.01E+13	32.8

Table 5-40 shows the TMDL, which is the amount of *E. coli* that the stream can receive in a given year while still meeting the water quality standard. The average annual loads were estimated using a five-year (2013-2017) water quality simulation and taking into consideration the hydrologic and environmental processes involving the fate and transport of bacteria. The TMDL WLA reflects a future growth allocation for potential new or expanding dischargers in the future. Any permittees discharging bacteria will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The Load Allocation is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined at the downstream end of the impaired segment, the watershed outlet. This value may be different from nonpoint source loads provided in Table 5-39 because of factors such as bacteria die-off that occur between the point of deposition and the modeled watershed outlet.

*Table 5-40. Mattaponi River TMDL (counts/year) for E. coli*

WLA	LA	MOS	TMDL
1.00E+12	4.91E+13	IMPLICIT	5.01E+13

The average annual *E. coli* loads were converted to daily loads using the approach discussed in section 5.6. The TMDL, expressed in daily loads, is given in Table 5-41.

*Table 5-41. Mattaponi River TMDL (counts/day) for E. coli*

WLA	LA	MOS	TMDL
2.74E+09	5.19E+11	IMPLICIT	5.22E+11

Figure 5-28 and Figure 5-29 show the 90-day geometric mean and daily average *E. coli* concentrations, respectively, under both the existing and the TMDL allocation conditions. Figure 5-30 shows the exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions. The figures also include the geometric mean and the statistical threshold value criteria as horizontal solid lines. The figures demonstrate that the developed TMDL ensures that, under the TMDL allocation conditions, both water quality criteria are met in the impaired segment of Mattaponi River.

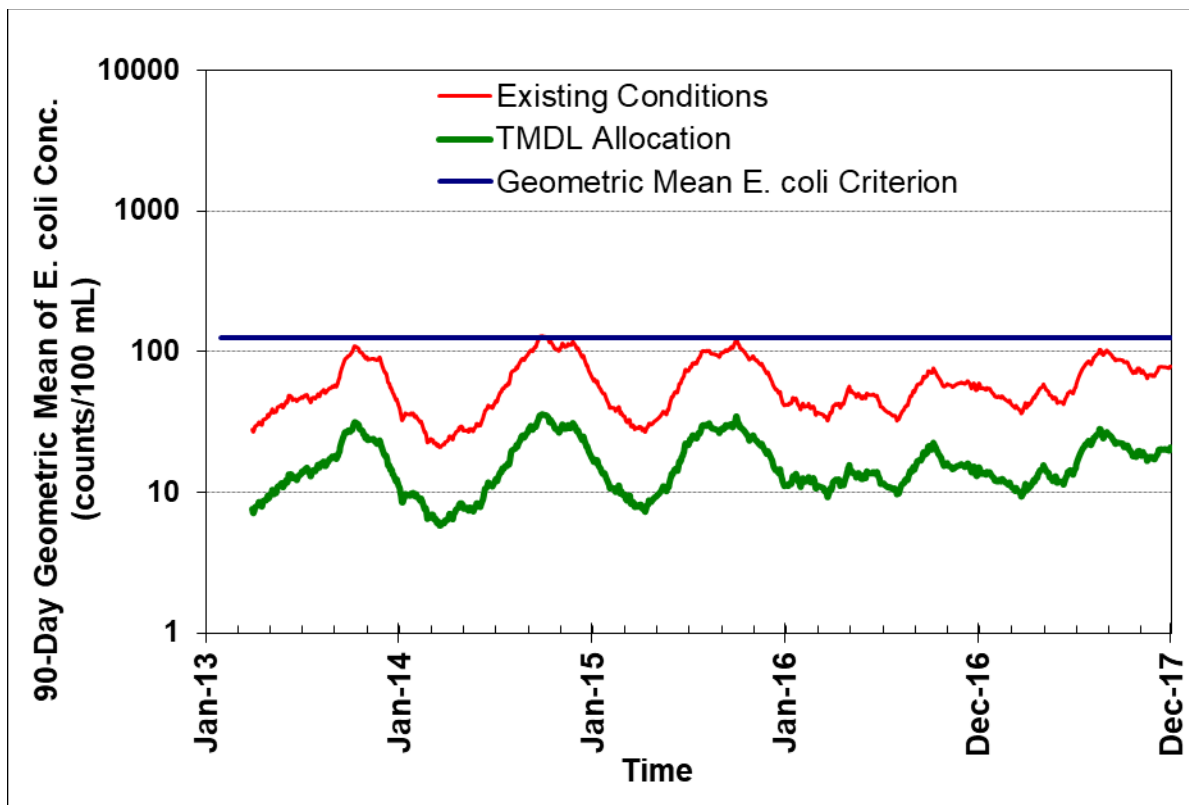
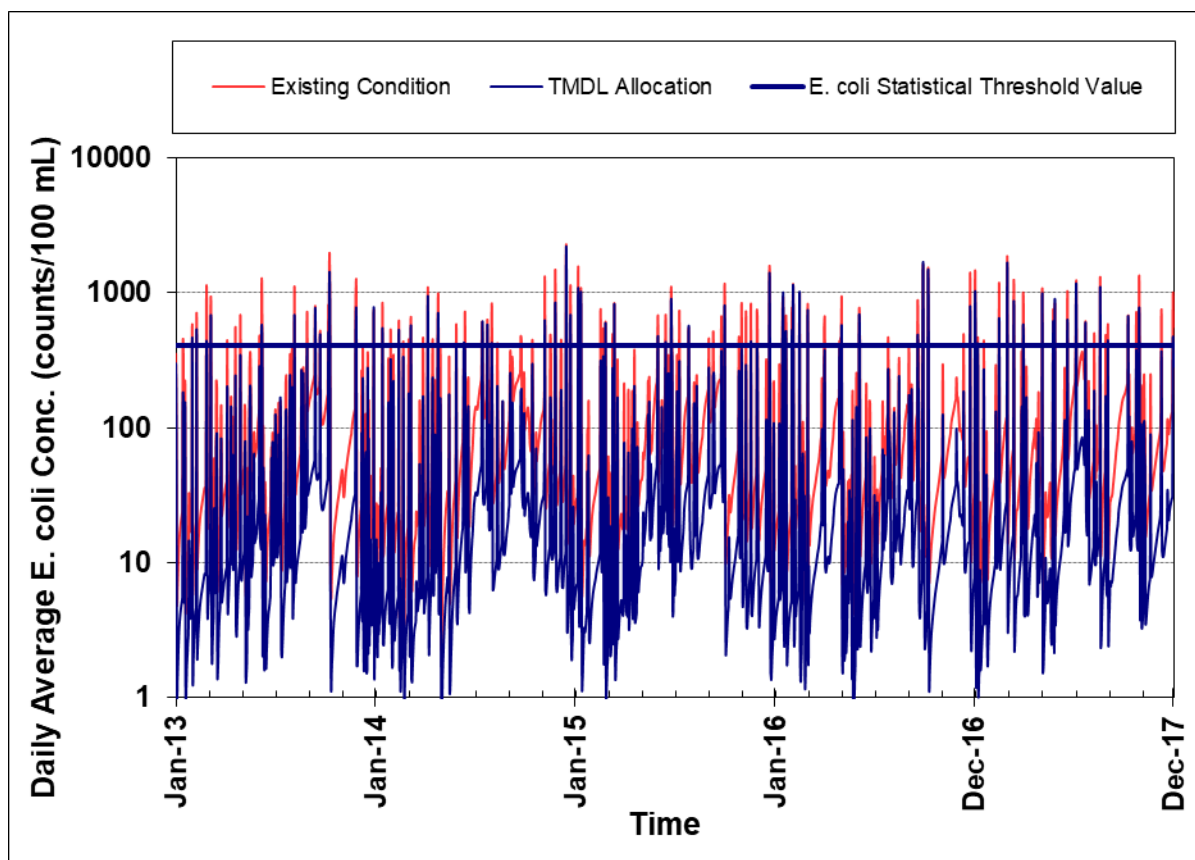
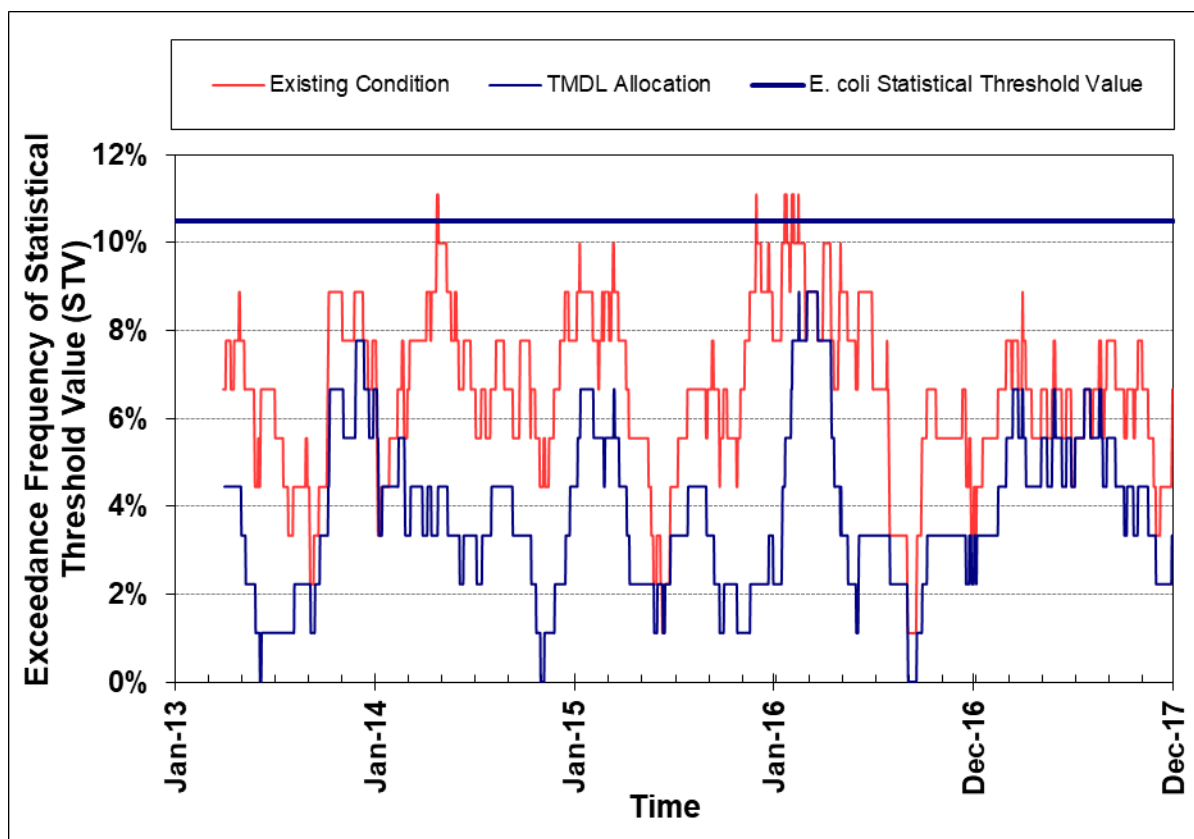


Figure 5-28. Mattaponi River the rolling 90-day geometric mean *E. coli* concentrations under existing and TMDL conditions



*Figure 5-29. Mattaponi River daily average *E. coli* concentrations under existing and TMDL conditions*



*Figure 5-30. Mattaponi River exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions*

#### 5.5.11 XDN-Garnetts Creek, UT (VAP-F23R\_XDN01A00)

The existing and allocated point and nonpoint source loads along with a TMDL summary for XDN-Garnetts Creek, UT are presented in this section.

##### *5.5.11.1 XDN-Garnetts Creek, UT Wasteload Allocation*

There are no permitted point sources in the XDN-Garnetts Creek, UT TMDL watershed; therefore, as outlined in DEQ recommendations (VADEQ, 2016a), two percent of the TMDL was set aside for future growth of developed land and residential human populations. The future growth value ( $2.65\text{E}+10$  counts per year *E. coli*) is assigned as the WLA in the XDN-Garnetts Creek, UT TMDL watershed

### 5.5.11.2 XDN-Garnetts Creek, UT Load Allocation Plan and TMDL Summary

The scenarios modeled to determine the TMDL allocation for the XDN-Garnetts Creek, UT TMDL watershed are listed in Table 5-42. No reductions in bacteria loads from forest and wetland were considered in any of the scenarios. According to the TMDL allocation scenario (number 5), the recommended reductions necessary for meeting the *E. coli* GM water quality criterion of 126 counts/100 ml and the statistical threshold value water quality criterion of 410 counts/100 ml for XDN-Garnetts Creek, UT are:

- 100% reduction of the human sources (failed septic systems and straight pipes)
- 26% reduction of the direct livestock in-stream loading
- 45% reduction of bacteria loading from nonpoint sources (pasture, hay, cropland, and developed land)

*Table 5-42. Bacteria load allocation scenarios for XDN-Garnetts Creek, UT TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml)*

Scenario	Failing Sewage Systems	Cattle Direct Deposition	Pasture	Hay	Cropland	Developed Land	Wildlife Direct Deposition	GM Exceedance Rate	STV Exceedance Rate
1	100	0	0	0	0	0	0	14	0.3
2	100	100	0	0	0	0	0	14	0.3
3	100	100	0	0	0	0	100	0	0.3
4	100	50	50	50	50	50	0	0	0
<b>5<sup>1</sup></b>	<b>100</b>	<b>26</b>	<b>45</b>	<b>45</b>	<b>45</b>	<b>45</b>	<b>0</b>	<b>0</b>	<b>0</b>

<sup>1</sup>Final TMDL Scenario

Table 5-43 shows the existing condition *E. coli* loads, load allocations under scenario 5 and the reductions required for different land use categories and direct sources within XDN-Garnetts Creek, UT watershed.

*Table 5-43. Annual load existing conditions and allocations and percent reduction per land use category for XDN-Garnetts Creek, UT TMDL Watershed*

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Forest and Wetland	2.65E+11	14.8	2.65E+11	0.0
Developed Land	7.48E+10	4.2	4.10E+10	45.1
Hay	1.72E+10	1.0	9.43E+09	45.1

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Pasture	9.37E+11	52.2	5.14E+11	45.1
Cropland	5.40E+10	3.0	2.96E+10	45.1
Cattle Direct Deposition	2.57E+10	1.4	1.89E+10	26.5
Wildlife Direct Deposition	4.21E+11	23.4	4.21E+11	0.0
Straight Pipes, Pit Privies, and Failing Septics	0.00E+00	0.0	0.00E+00	100.0
Point Source	0.00E+00	0.0	0.00E+00	0.0%
Future Growth	-	-	2.65E+10	-
Total Loads	1.79E+12	100.0	1.33E+12	26.1%

Table 5-44 shows the TMDL, which is the amount of *E. coli* that the stream can receive in a given year while still meeting the water quality standard. The average annual loads were estimated using a five-year (2013-2017) water quality simulation and taking into consideration the hydrologic and environmental processes involving the fate and transport of bacteria. The TMDL WLA reflects a future growth allocation for potential new or expanding dischargers in the future. Any permittees discharging bacteria will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The Load Allocation is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined at the downstream end of the impaired segment, the watershed outlet. This value may be different from nonpoint source loads provided in Table 5-43 because of factors such as bacteria die-off that occur between the point of deposition and the modeled watershed outlet.

*Table 5-44. XDN-Garnetts Creek, UT TMDL (counts/year) for E. coli*

WLA	LA	MOS	TMDL
2.65E+10	1.30E+12	IMPLICIT	1.33E+12

The average annual *E. coli* loads were converted to daily loads using the approach discussed in section 5.6. The TMDL, expressed in daily loads, is given in Table 5-45.

*Table 5-45. XDN-Garnetts Creek, UT TMDL (counts/day) for E. coli*

WLA	LA	MOS	TMDL
7.26E+07	1.36E+10	IMPLICIT	1.36E+10

Figure 5-31 and Figure 5-32 show the 90-day geometric mean and daily average *E. coli* concentrations, respectively, under both the existing and the TMDL allocation conditions. Figure 5-33 shows the exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions. The figures also include the geometric mean and the statistical threshold value criteria as horizontal solid lines. The figures demonstrate that the developed TMDL ensures that, under the TMDL allocation conditions, both water quality criteria are met in the impaired segment of XDN-Garnetts Creek, UT.

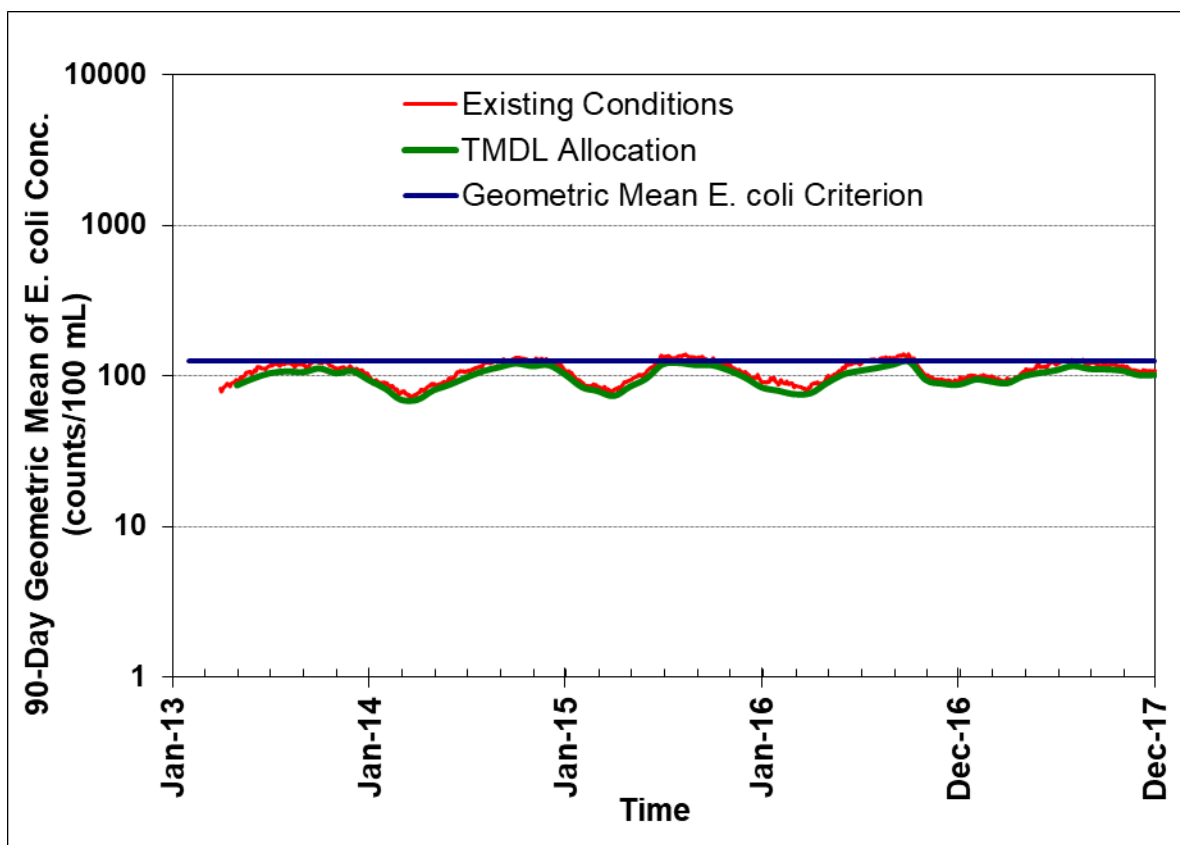
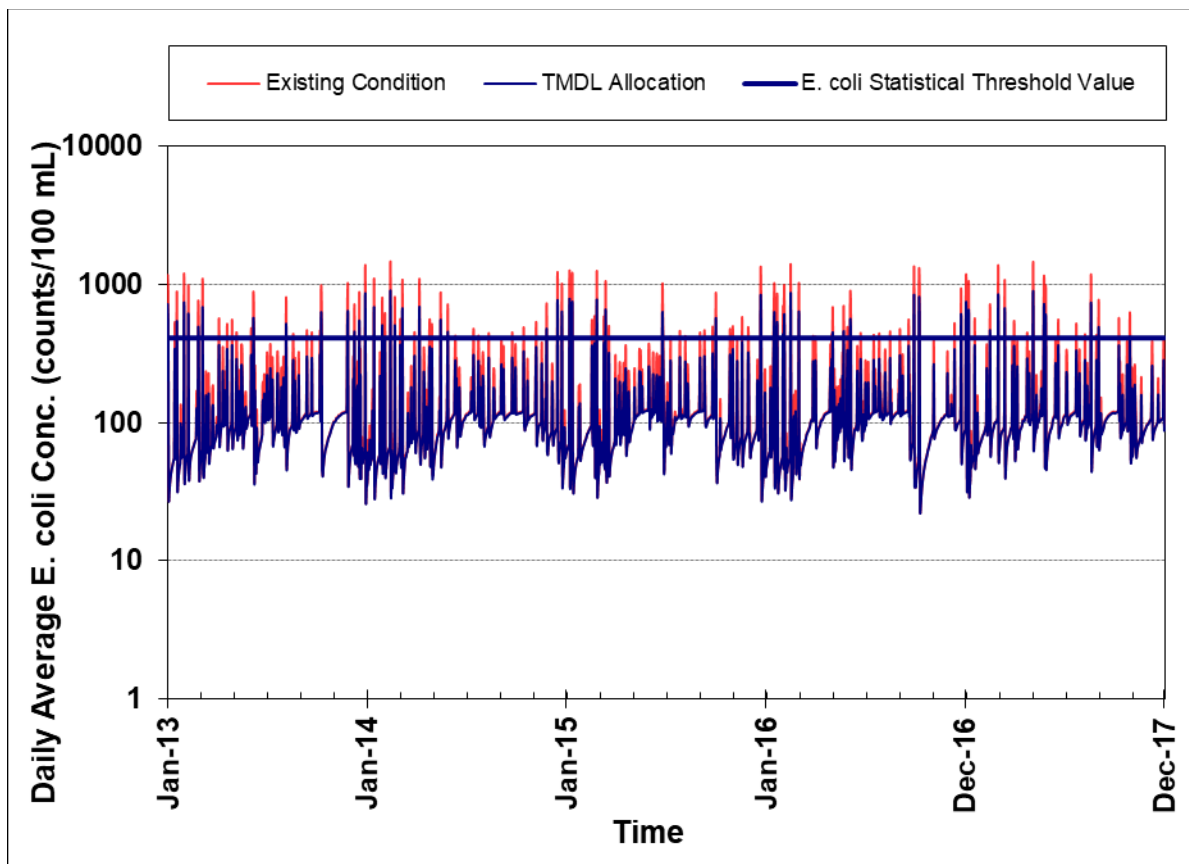


Figure 5-31. XDN-Garnetts Creek, UT the rolling 90-day geometric mean *E. coli* concentrations under existing and TMDL conditions



*Figure 5-32. XDN-Garnetts Creek, UT daily average E. coli concentrations under existing and TMDL conditions*

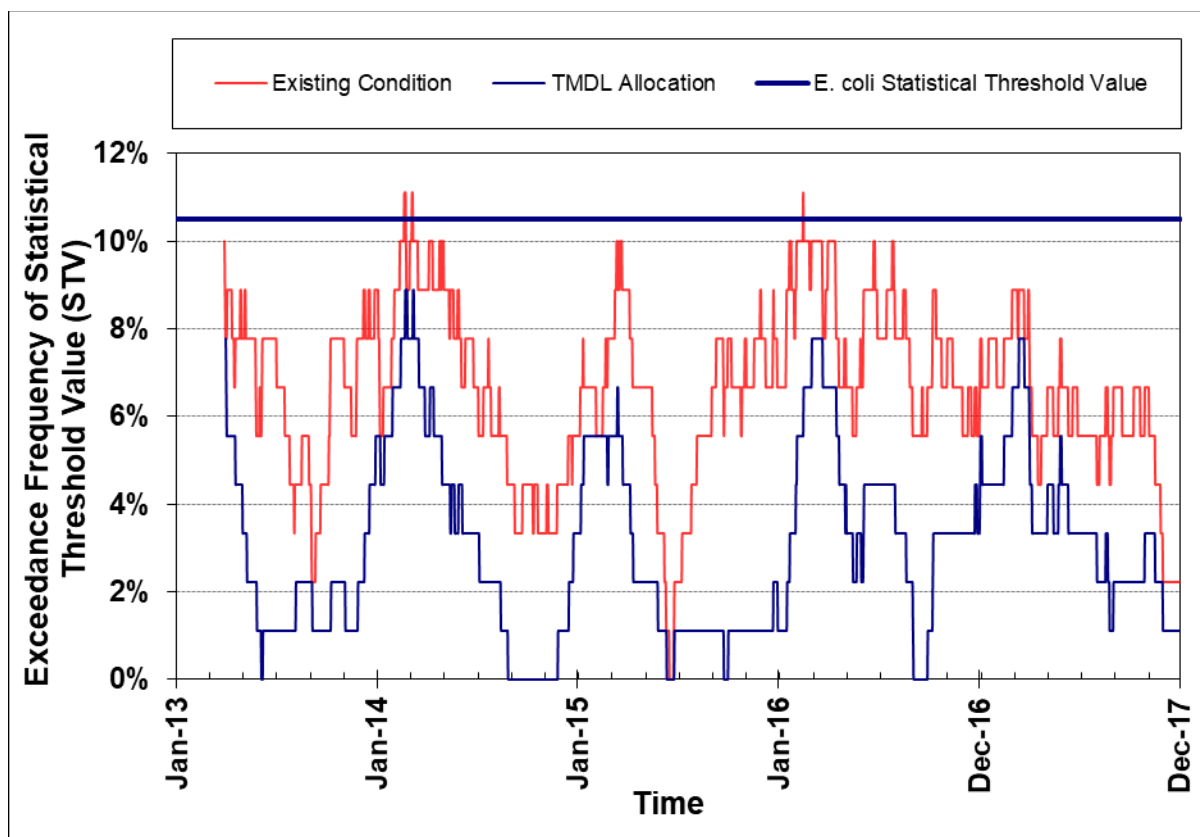


Figure 5-33. XDN-Garnetts Creek, UT exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions

#### 5.5.12 XJG-Dickeys Swamp, UT (VAP-F23R\_XJG01A14)

The existing and allocated point and nonpoint source loads along with a TMDL summary for XJG-Dickeys Swamp, UT are presented in this section.

##### 5.5.12.1 XJG-Dickeys Swamp, UT Wasteload Allocation

There are no permitted point sources in the XJG-Dickeys Swamp, UT TMDL watershed; therefore, as outlined in DEQ recommendations (VADEQ, 2016a), two percent of the TMDL was set aside for future growth of developed land and residential human populations. The future growth value (2.01E+10 counts per year *E. coli*) is assigned as the WLA in the XJG-Dickeys Swamp, UT TMDL watershed

### 5.5.12.2 XJG-Dickeys Swamp, UT Load Allocation Plan and TMDL Summary

The scenarios modeled to determine the TMDL allocation for the XJG-Dickeys Swamp, UT TMDL watershed are listed in Table 5-46. No reductions in bacteria loads from forest and wetland were considered in any of the scenarios. According to the TMDL allocation scenario (number 5), the recommended reductions necessary for meeting the *E. coli* GM water quality criterion of 126 counts/100 ml and the statistical threshold value water quality criterion of 410 counts/100 ml for XJG-Dickeys Swamp, UT are:

- 100% reduction of the human sources (failed septic systems and straight pipes)
- 80% reduction of the direct livestock in-stream loading
- 43% reduction of bacteria loading from nonpoint sources (pasture, hay, cropland, and developed land)

*Table 5-46. Bacteria load allocation scenarios for XJG-Dickeys Swamp, UT TMDL Watershed, showing percent reductions to existing bacteria loads for each land use source and resulting exceedance rates of the GM (126 counts/100 ml) and STV (410 counts/100 ml)*

Scenario	Failing Sewage Systems	Cattle Direct Deposition	Pasture	Hay	Cropland	Developed Land	Wildlife Direct Deposition	GM Exceedance Rate	STV Exceedance Rate
1	100	0	0	0	0	0	0	24	41
2	100	100	0	0	0	0	0	24	41
3	100	100	0	0	0	0	100	0	11
4	100	50	50	50	50	50	0	0	0
<b>5<sup>1</sup></b>	<b>100</b>	<b>80</b>	<b>43</b>	<b>43</b>	<b>43</b>	<b>43</b>	<b>0</b>	<b>0</b>	<b>0</b>

<sup>1</sup>Final TMDL Scenario

Table 5-47 shows the existing condition *E. coli* loads, load allocations under scenario 5 and the reductions required for different land use categories and direct sources within XJG-Dickeys Swamp, UT watershed.

*Table 5-47. Annual load existing conditions and allocations and percent reduction per land use category for XJG-Dickeys Swamp, UT TMDL Watershed*

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Forest and Wetland	2.56E+11	21.7	2.56E+11	0.0
Developed Land	6.31E+10	5.3	3.59E+10	43.2
Hay	6.99E+09	0.6	3.97E+09	43.2

Land Use Category	Existing Conditions Load (counts/year)	% of Total Load	Load Allocation (counts/year)	Reduction (%)
Pasture	2.64E+11	22.4	1.50E+11	43.2
Cropland	6.73E+10	5.7	3.82E+10	43.2
Cattle Direct Deposition	2.58E+10	2.2	5.06E+09	80.4
Wildlife Direct Deposition	4.96E+11	42.1	4.96E+11	0.0
Straight Pipes, Pit Privies, and Failing Septics	0.00E+00	0.0	0.00E+00	100.0
Point Source	0.00E+00	0.0	0.00E+00	0.0
Future Growth	-	-	2.01E+10	-
Total Loads	1.18E+12	100.0	1.01E+12	14.7

Table 5-48 shows the TMDL, which is the amount of *E. coli* that the stream can receive in a given year while still meeting the water quality standard. The average annual loads were estimated using a five-year (2013-2017) water quality simulation and taking into consideration the hydrologic and environmental processes involving the fate and transport of bacteria. The TMDL WLA reflects a future growth allocation for potential new or expanding dischargers in the future. Any permittees discharging bacteria will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The Load Allocation is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined at the downstream end of the impaired segment, the watershed outlet. This value may be different from nonpoint source loads provided in Table 5-47 because of factors such as bacteria die-off that occur between the point of deposition and the modeled watershed outlet.

*Table 5-48. XJG-Dickeys Swamp, UT TMDL (counts/year) for E. coli*

WLA	LA	MOS	TMDL
2.01E+10	9.86E+11	IMPLICIT	1.01E+12

The average annual *E. coli* loads were converted to daily loads using the approach discussed in section 5.6. The TMDL, expressed in daily loads, is given in Table 5-49.

*Table 5-49. XJG-Dickeys Swamp, UT TMDL (counts/day) for E. coli*

WLA	LA	MOS	TMDL
5.51E+07	1.04E+10	IMPLICIT	1.05E+10

Figure 5-34 and Figure 5-35 show the 90-day geometric mean and daily average *E. coli* concentrations, respectively, under both the existing and the TMDL allocation conditions. Figure 5-36 shows the exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions. The figures also include the geometric mean and the statistical threshold value criteria as horizontal solid lines. The figures demonstrate that the developed TMDL ensures that, under the TMDL allocation conditions, both water quality criteria are met in the impaired segment of XJG-Dickeys Swamp, UT.

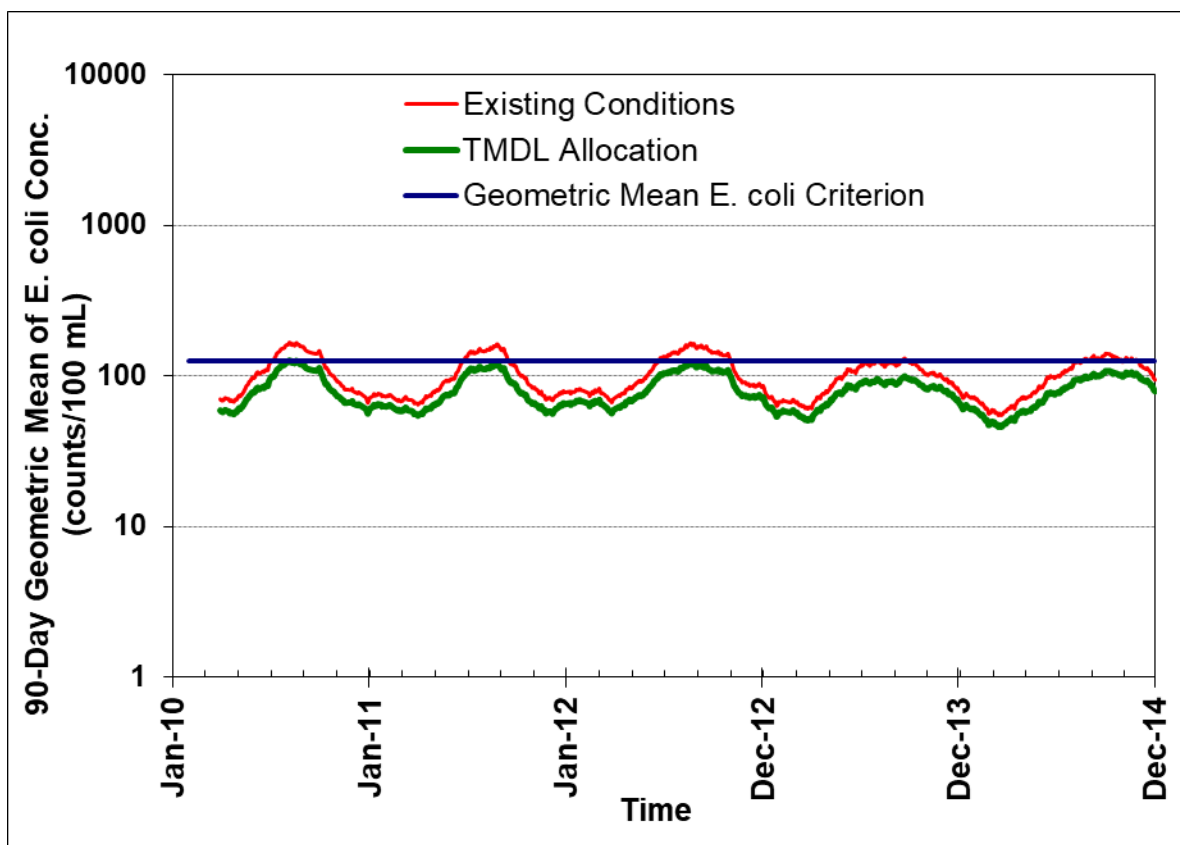


Figure 5-34. XJG-Dickeys Swamp, UT the rolling 90-day geometric mean *E. coli* concentrations under existing and TMDL conditions

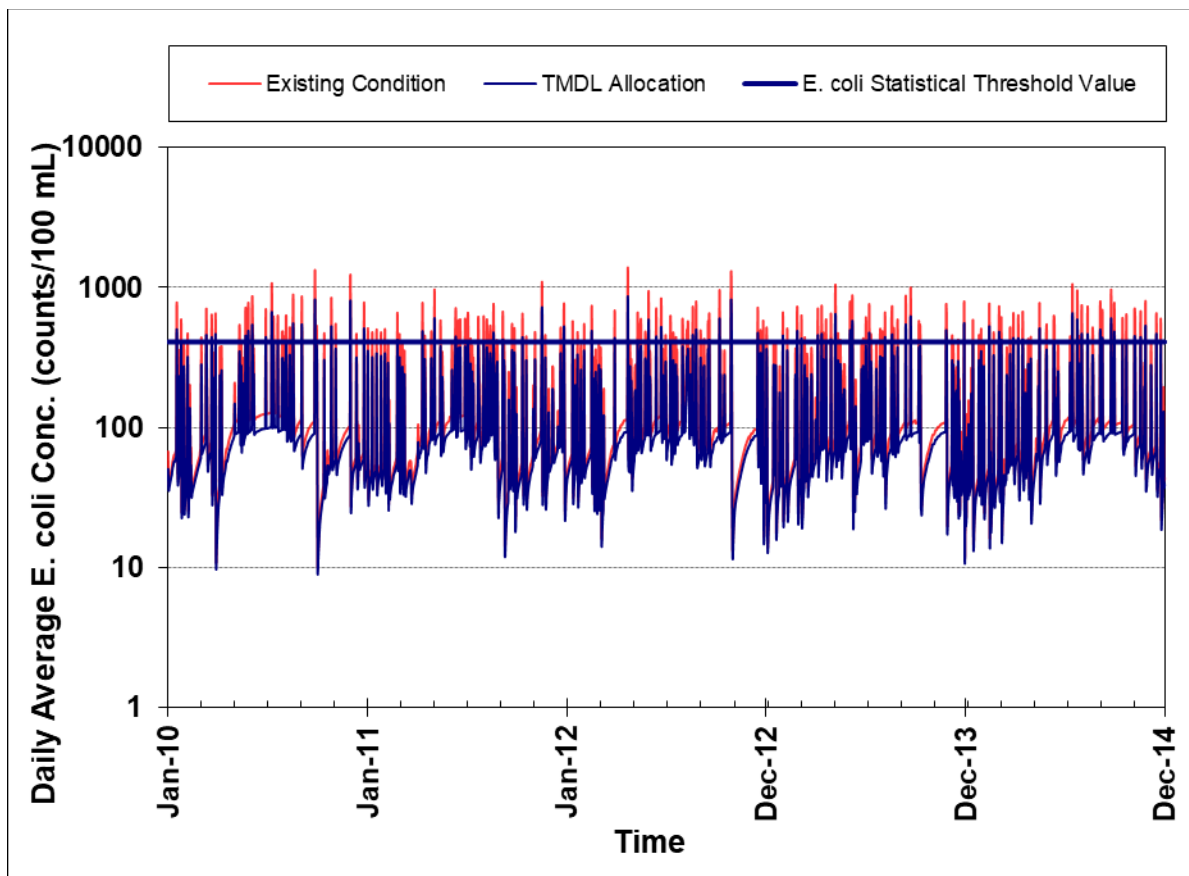


Figure 5-35. XJG-Dickeys Swamp, UT daily average *E. coli* concentrations under existing and TMDL conditions

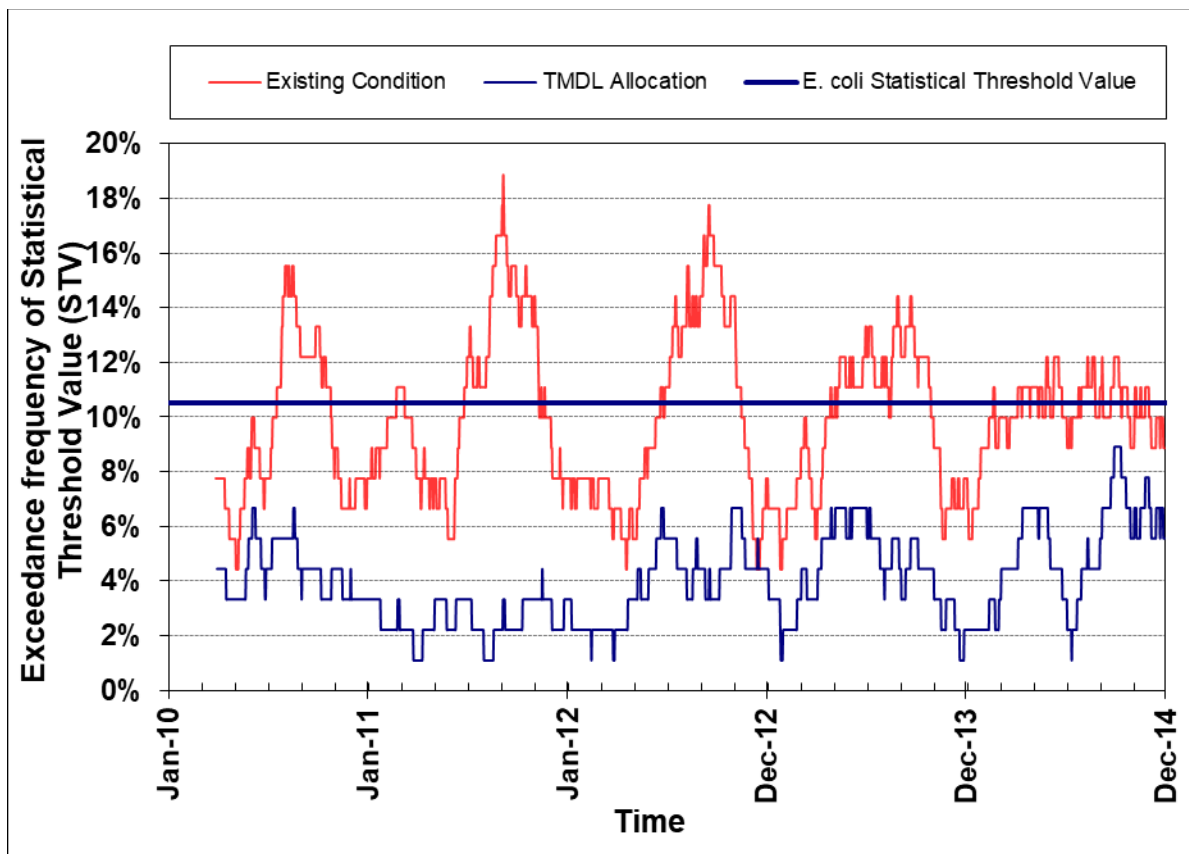


Figure 5-36. XJG-Dickeys Swamp, UT exceedance frequency of the STV based on the rolling 90-day average *E. coli* concentrations under existing and TMDL conditions

## 5.6 The Final Total Maximum Daily Loads

The EPA (2007) recommends that TMDLs and their associated load allocations and wasteload allocations include a daily time increment. So in conjunction with the annual TMDLs discussed in the previous sections and summarized below (Table 5-50), a daily TMDL was provided. The daily TMDLs were calculated using the following approach. According to the EPA, the long-term average *E. coli* loads and coefficient of variations should be determined at the outlet of the impaired segments to implement the final allocation scenarios and express the TMDL on a daily basis. Assuming a log-normal distribution of data, the maximum daily loads should be determined using the following equation:

$$MDL = LTA \times \text{Exp}[za - 0.5a^2]$$

Where:

MDL = maximum daily limit (counts/day)

LTA = long-term average (counts/day)

z = z statistic of the probability of occurrence

$a^2 = \ln(CV^2 + 1)$

CV = coefficient of variation

This formula was utilized in calculating the daily LAs for nonpoint sources by applying the LTA and using a probability of occurrence of 95% for each impaired segment. The formula was also used to calculate the max daily WLAs for point sources by applying the LTA for each annual WLA. Considering an implicit MOS, the sum of the WLAs, FG, and LAs provides the TMDL as the daily maximum values.

*Table 5-50. Estimated Annual Loads and Load Reductions of E. coli: Combined WLA and LA*

Stream	Assessment Unit	Existing Load (Counts/Year)	Allowable Load (Counts/Year)	Reduction (%)	MOS
Aylett	VAP-F23R_AYL01A12	1.24E+13	1.21E+13	2.5%	Implicit
Courthouse Creek	VAP-F24R_CTH01A00	7.26E+12	7.05E+12	2.8%	Implicit
Dickeys Swamp	VAP-F23R_DKW01B00	1.16E+13	1.11E+13	4.6%	Implicit
Dogwood Fork	VAP-F23R_DWD01A00	1.12E+12	8.97E+11	19.8%	Implicit
Dorrell Creek	VAN-F21R_DRL01A18	3.21E+12	2.88E+12	10.5%	Implicit

Stream	Assessment Unit	Existing Load (Counts/Year)	Allowable Load (Counts/Year)	Reduction (%)	MOS
Garnetts Creek	VAP-F23R_GNT01A00	4.56E+12	4.36E+12	4.4%	Implicit
Gravel Run	VAN-F21R_GVL01A18	6.71E+12	5.50E+12	18.0%	Implicit
Herring Creek	VAN-F21R_HER01B02 VAN-F21R_HER01A06	3.01E+13	2.83E+13	5.7%	Implicit
Market Swamp	VAP-F23R_MKT01B00	6.15E+12	5.49E+12	10.6%	Implicit
Mattaponi River (non-tidal)	VAP-F21R_MPN01C02 VAP-F21R_MPN01B02	7.45E+13	5.01E+13	32.8%	Implicit
XDN-Garnetts Creek, UT	VAP-F23R_XDN01A00	1.79E+12	1.33E+12	26.1%	Implicit
XJG-Dickeys Swamp, UT	VAP-F23R_XJG01A14	1.18E+12	1.01E+12	14.7%	Implicit

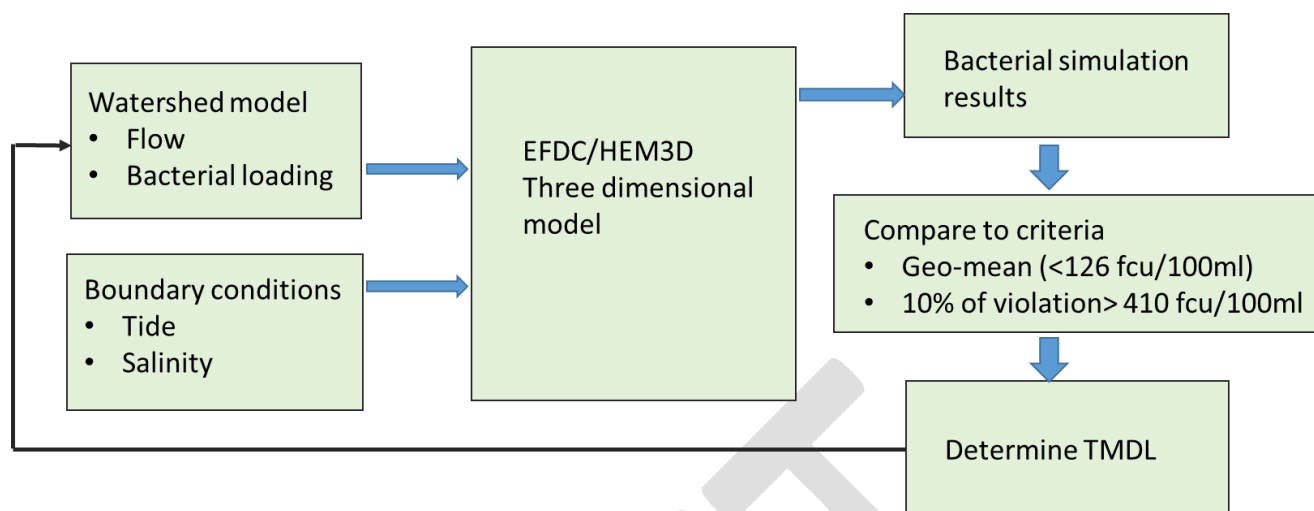
## 6 3D MODEL DEVELOPMENT AND TMDL ALLOCATION (TIDAL)

---

### 6.1 Description of the EFDC Model

The 3-dimensional Environmental Fluid Dynamics Computer Code (EFDC) (Hamrick, 1992; Park et al., 1995) was used to simulate the bacteria transport in the Mattaponi River estuary. This model has been integrated into the EPA's TMDL Modeling Toolbox for supporting TMDL development (<http://www.epa.gov/exposure-assessment-models/efdc>).

The EFDC model uses a computational grid to represent the study area. The grid is comprised of cells connected through the modeling process. The grid resolution (cell size) determines the level of spatial resolution in the model and the model efficiency. From an operational perspective, the smaller the cell size, the higher the resolution and the lower the computational efficiency. The freshwater flows and bacteria loadings from the watershed adjacent to the tidal portion of the Mattaponi River are simulated by the Loading Simulation Program in C++ (LSPC) watershed model (Shen et al., 2005), while the flow and loading from upper stream of the tidal Mattaponi River are output from the HSPF watershed model (see previous section). These flows and loadings are fed into the adjacent EFDC model segments. The LSPC watershed model includes selected Hydrologic Simulation Program FORTRAN (HSPF) algorithms for simulating hydrology, sediment, and general water quality on land, as well as a simplified stream transport model (Bicknell et al., 1996; VADEQ, 2012). Figure 6-1 shows the modeling process.



*Figure 6-1. Modeling process for the bacteria TMDL*

## 6.2 Model Setup

The EFDC model has been applied to the York River to study the sea level rise and its impacts on the York River (Rice et al. 2011) and on freshwater withdrawal in the Pamunkey River (Shen et al., 2017). The Mattaponi River portion of the model was used for this project (Figure 6-2). There are a total of 649 cells in the horizontal layer for the Mattaponi River, and the grid sizes range from 15m to 500m in horizontal direction along the river and 3 grids are used in cross-section. There are eight vertical layers to represent the depth of the Mattaponi River tidal segment. The nonpoint sources are discharged to the estuary through the major streams. The dominant inflow is from upstream. The existing condition annual loads for each land use category were determined for the two impaired stream segments in the Mattaponi River tidal TMDL watershed (Table 6-1 and Table 6-2).

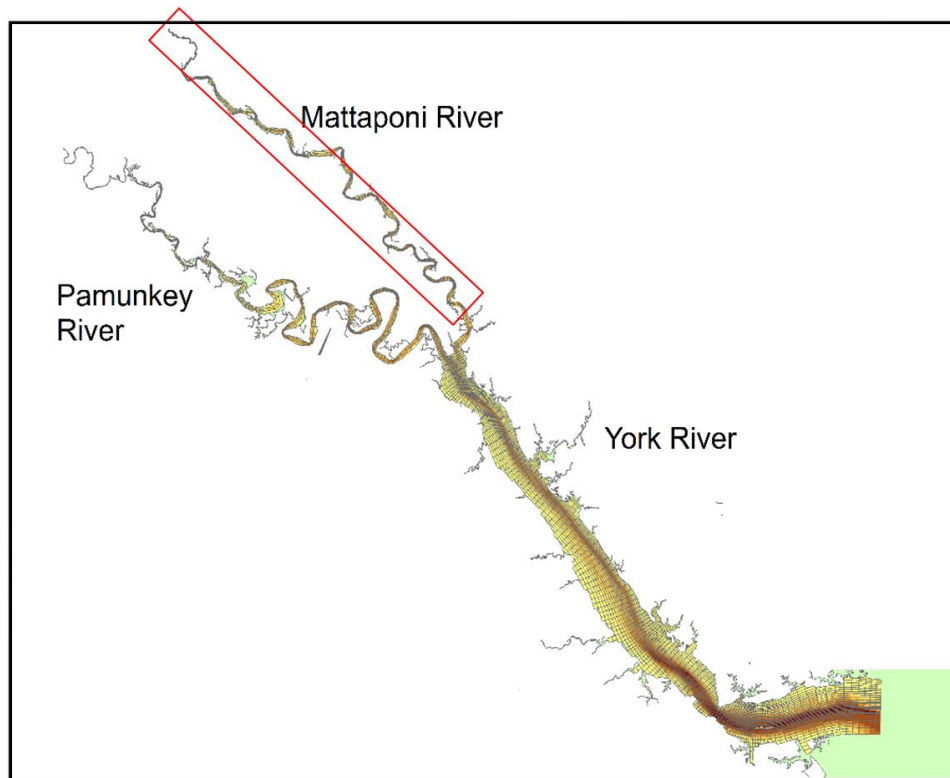
*Table 6-1. Existing condition annual loads per land use category for the tidal Mattaponi River (VAP-F23E\_MPN03A06) TMDL Watershed*

Land use category	Existing Load (count/year)	% of Total Load
Forest and Wetland	2.48E+12	17.59%
Developed Land	6.17E+11	4.38%
Hay	6.81E+10	0.48%
Pasture	2.08E+12	14.75%
Cropland	1.08E+12	7.66%

Land use category	Existing Load (count/year)	% of Total Load
Cattle Direct Deposition	1.40E+10	0.10%
Wildlife Direct Deposition	7.73E+12	54.82%
Straight Pipes, Pit Privies, and Failing Septics	2.33E+10	0.17%
Point Source	0.00E+00	0.00%
Total Loads	1.41E+13	100.00%

*Table 6-2. Existing condition annual loads per land use category for the tidal Mattaponi River (VAP-F24E\_MPN03A98) TMDL Watershed*

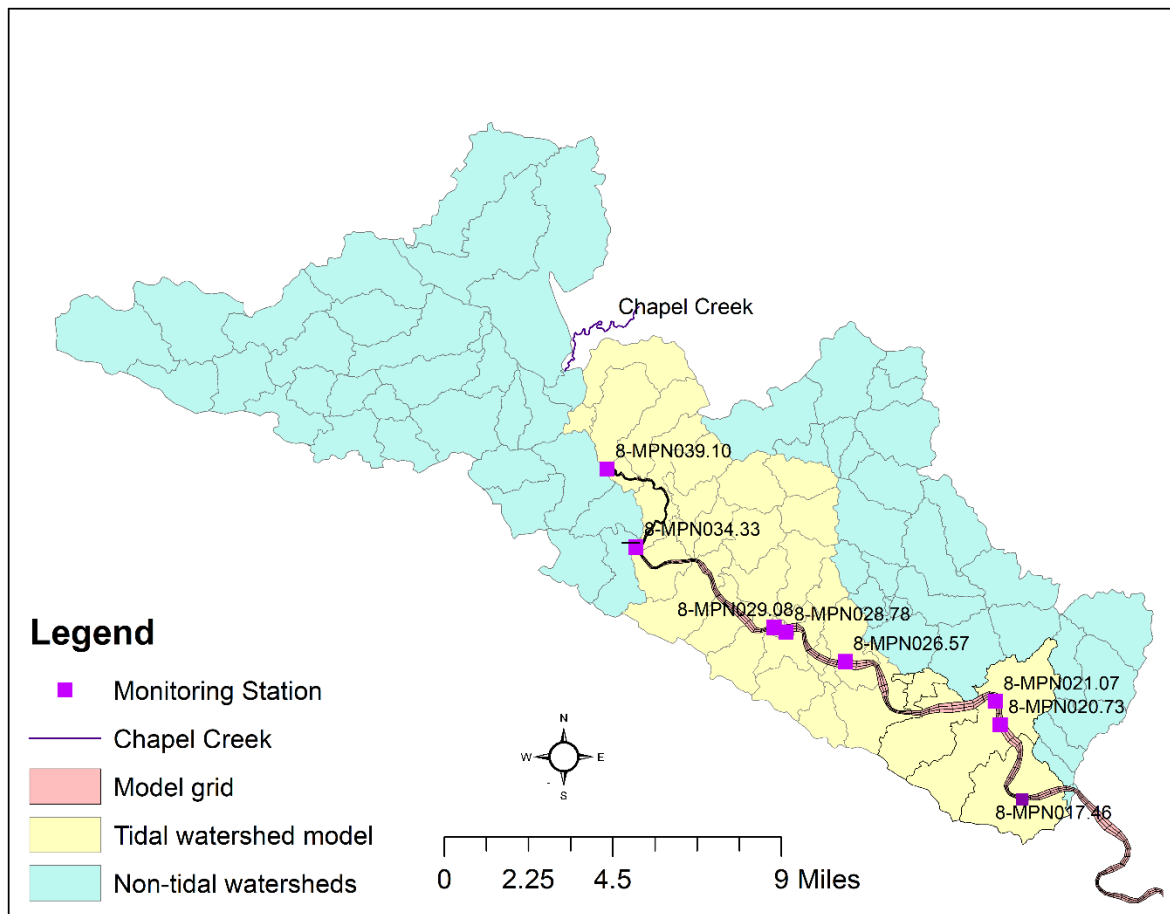
Land use category	Existing Load (count/year)	% of Total Load
Forest and Wetland	1.07E+12	23.88%
Developed Land	2.09E+11	4.67%
Hay	1.08E+10	0.24%
Pasture	3.86E+11	8.62%
Cropland	1.17E+11	2.61%
Cattle Direct Deposition	6.74E+09	0.15%
Wildlife Direct Deposition	3.00E+12	66.96%
Straight Pipes, Pit Privies, and Failing Septics	3.89E+10	0.87%
Point Source	0.00E+00	0.00%
Total Loads	4.48E+12	100%



*Figure 6-2. York River model domain with the modelling grids, project area outlined in red*

The EFDC model was calibrated for salinity and bacteria concentration. The model is forced by tide at the open boundary (West Point, VA) using NOAA observations at Gloucester Point (Station ID: 8637624) and the York River model. The salinity is from the output of the York River model combined with NOAA shallow water observations in the York River. Besides the tidal forcing at the downstream boundary and freshwater discharge, wind is the only weather data necessary for the hydrodynamic model. The wind data were obtained from the Richmond Airport. The model was forced by the freshwater input from upstream and lateral runoff. The modeled upstream hourly flow from 01/01/2013 to 12/31/2017 was provided by Streams Tech, Inc. The lateral inflow (01/01/2013 - 12/31/2017) was simulated by VIMS and Streams Tech, Inc. Figure 6-3 shows the watersheds and water quality monitoring stations used. Chapel Creek is also located in the upper stream of the tidal Mattaponi River and the TMDL for Chapel Creek was completed. Both flow and bacterial loadings (existing condition and TMDL) are also discharges to the Mattaponi, respectively for existing condition and TMDL runs. The hourly

bacterial loadings simulated by the HSPF watershed model (described in Section 4) were fed to the EFDC model at the discharge locations. The model simulation period is from 2013-2017 with a time step of 20 seconds.

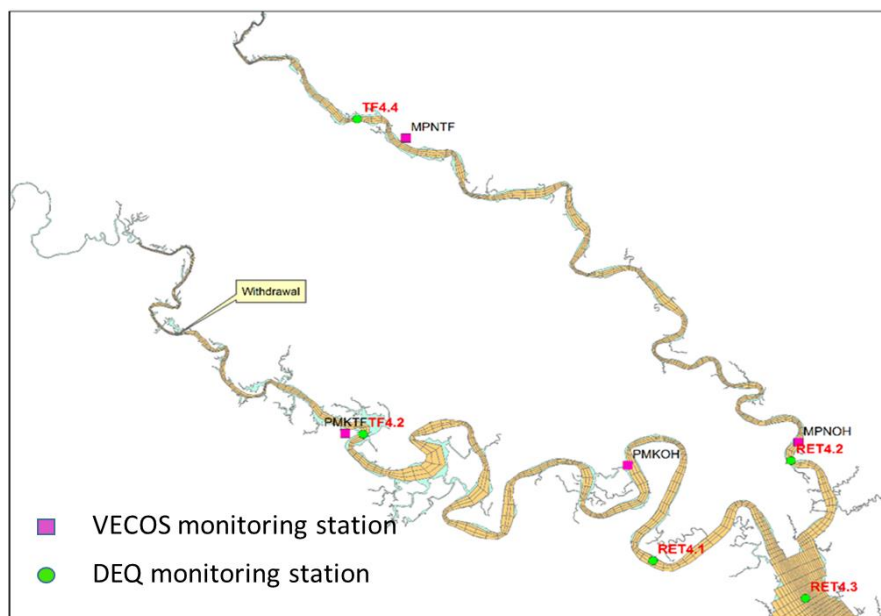


*Figure 6-3. Map of TMDL subwatersheds and water quality stations*

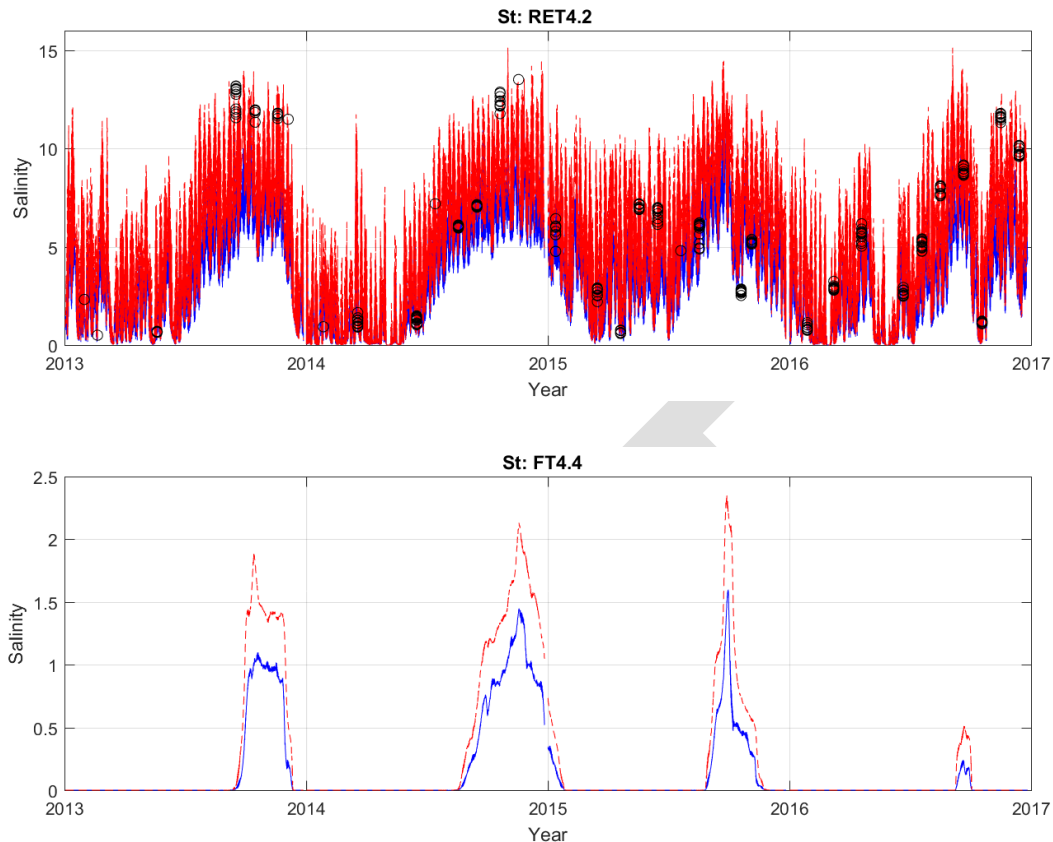
### 6.3 Model Calibration of Salinity

An accurate simulation of salinity is very important for the model to correctly simulate estuarine circulation and transport processes of bacteria. There are two DEQ salinity observation stations in the Mattaponi River estuary, which are TF4.4 and RET4.2 (Figure 6-5). Station TF4.4 is a tidal freshwater station, where salinity is very low and not measured routinely. Virginia Estuarine and Coastal Observing System (VECOS) has monitoring stations in the Mattaponi River from 2003-2005, which does not include the simulation period. The model-data

comparison focuses on Station RET4.2. The salinity is driven by freshwater inflow, tide, and wind. Rainfall contribution to the Mattaponi River is minor compared to surface runoff and is not included in the model simulation. When freshwater discharge is large, low salinity can be observed. When tide is dominant, high salinity can be observed. The upper panel of Figure 6-5 shows the comparison of modeled and observed salinity at Station RET4.2. The model captures both the magnitude and trend of the salinity very well. The lower panel of Figure 6-5 shows there is almost no salinity at Station TF4.4 (no observations were made during this period, only modeled salinity is shown).



*Figure 6-4. Mattaponi River salinity observation stations*

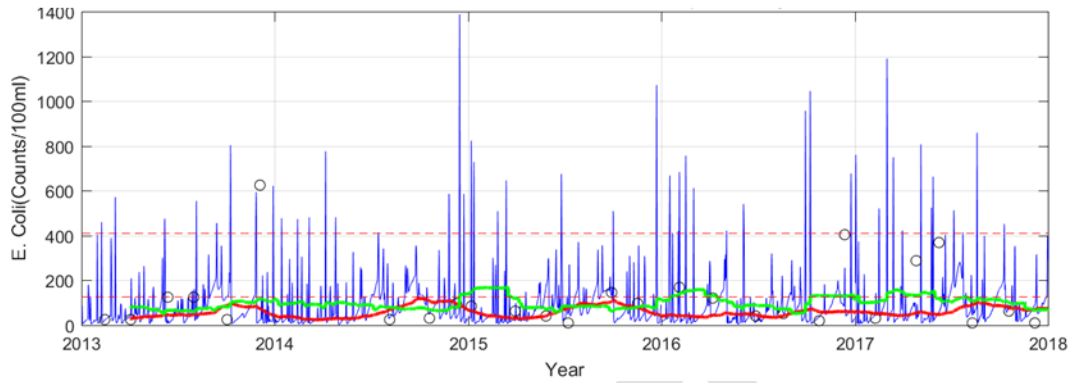


*Figure 6-5. Modeled (lines) and observed (circles) salinities at station RET4.2 (upper panel) and modeled salinity at TF4.4 (no observed data during this period) (lower panel) in the Mattaponi River (red lines are at the river bottom and blue lines are at the surface).*

## 6.4 Model Calibration of Bacteria

Calibration of the bacteria transport model is typically performed using water quality measurements. The 5-year model simulation results (2013-2017) are presented in Figure 6-6 and Figure 6-7 for the four DEQ monitoring stations (See previous sections for the station locations and data description). The model simulates the observations well for both the exceedance rates and observation ranges. The STV of 410 counts/100 ml is shown by the upper dashed line in the figures and the GM (126 counts/100 ml) is shown by the lower dashed line in the figures. Rolling 90-day geometric mean is also plot on figure (red lines).

### St: 8-MPN039.10



### St: 8-MPN034.33

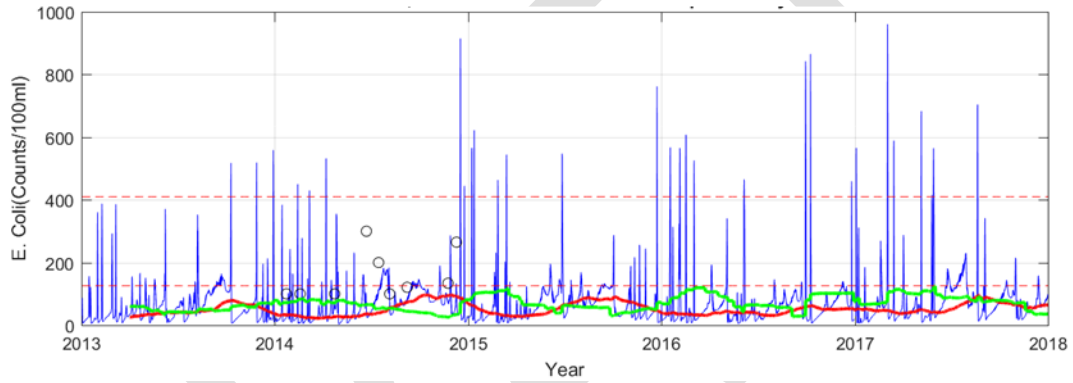


Figure 6-6. Modeled (solid blue lines) and observed (circles) bacteria concentrations, and rolling 90-day GM (solid red lines) and rolling 90-day STV (solid green lines) at two DEQ monitoring stations. The dashed red lines are GM (126 counts/100 ml) and STV (410 counts/100 ml).

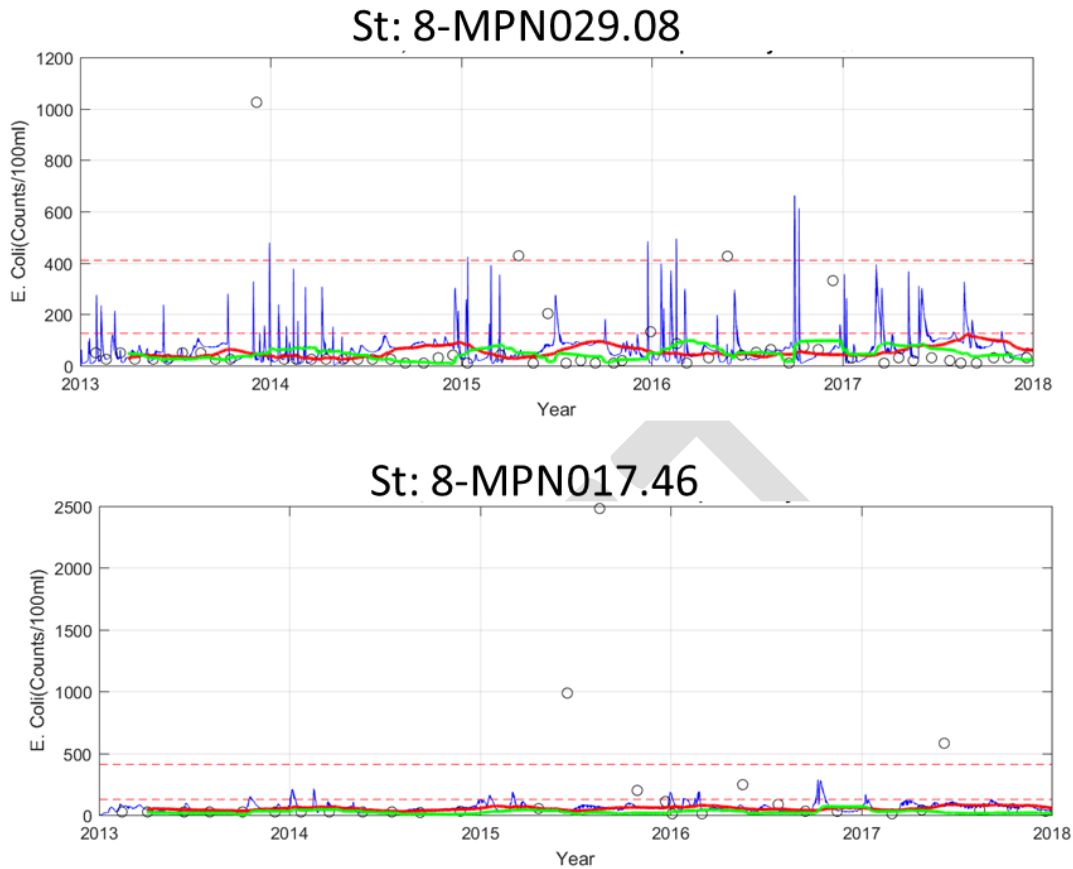


Figure 6-7. Modeled (solid blue lines) and observed (circles) bacteria concentrations, and rolling 90-day GM (solid red lines) at two DEQ monitoring stations. The dashed red lines are GM (126 counts/100 ml) and STV (410 counts/100 ml).

## 6.5 Model Simulation of TMDL

To determine allowable loads and develop TMDLs, loadings from the upstream non-tidal watersheds were reduced so that the receiving water bacterial concentration will meet the water quality standard (WQS) endpoints. The attainment of the WQS is assessed at each station for the geometric mean of 126 counts/100 ml (rolling 90-day period) and for the STV of 410 counts/100 ml which cannot have an excursion frequency of more than 10% in any rolling 90-day for *E. coli*. The most protective criterion should be used for determining the reduction. For a conservative approach, the model was initialized with high bacteria concentrations of observations. The result shows that when bacterial loadings are reduced sufficiently from the upper streams (non-tidal) watersheds to allow those receiving streams to attain WQS, no additional load reductions are needed from the watersheds adjacent to the Mattaponi River tidal

impairments. It is assumed that upstream reaches will attain WQS once appropriate BMPs, etc have been installed to sufficiently reduce bacteria however, if needed, BMPs may be considered for the tidal watersheds as well. Figure 6-8 shows the simulation of bacterial concentration after reducing loadings from upstream.

DRAFT

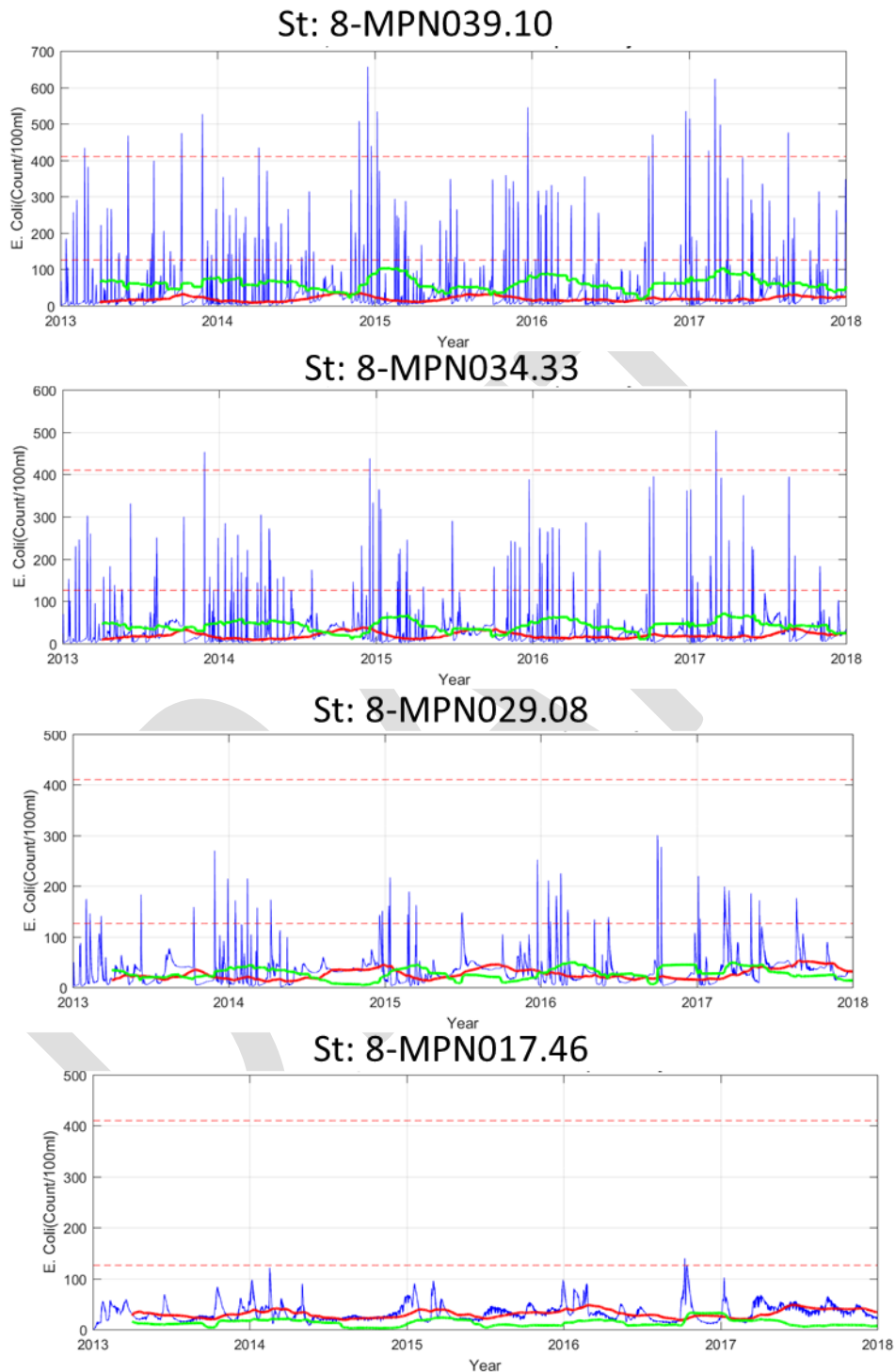


Figure 6-8. Modeled (blue solid lines), rolling 90-day GM (solid red lines), rolling 90-day STV (solid green lines) at four DEQ monitoring stations. The dashed red lines are GM (126 counts/100 ml) and STV (410 counts/100 ml).

Table 6-3 and Table 6-4 summarize the TMDLs for daily and annual loadings, respectively. For daily TMDLs, the EPA recommended statistical adjustment based on the simulated long-term mean daily loading was applied (USEPA, 2007). This method is described in Section 5.6. The annual TMDL is the LTA times 365.25 days.

*Table 6-3. Daily E. coli TMDL for the Mattaponi River Tidal Segment (Counts/Day)*

WLA (counts/day)	LA (counts/day)	MOS (5%)	Future Growth (2%)	TMDL (counts/day)
0.0	5.32E+10	2.86E+9	1.14E+9	5.72E+10

*Table 6-4. Annual E. coli TMDL for the Mattaponi River Tidal Segment (Counts /Year)*

WLA (counts/year)	LA (counts/year)	MOS (5%)	Future Growth (2%)	TMDL (counts/year)
0.0	8.68E+12	4.67E+11	1.87E+11	9.33E+12

## 7 IMPLEMENTATION AND REASONABLE ASSURANCES

---

Once a TMDL has been approved by EPA, measures must be taken to reduce pollutant loads from both point and nonpoint sources. The regulatory process involving TMDLs to improve water quality involves three steps: (1) development of TMDL(s), (2) development of an Implementation Plan (IP), which focuses primarily on nonpoint source controls, and (3) implementation of the measures outlined in the TMDL IP and water quality monitoring to evaluate progress and determine attainment of water quality standards. The following sections outline the framework used in the Virginia to provide reasonable assurance that the required pollutant reductions can be achieved.

### 7.1 Continuing Planning Process and Water Quality Management Planning

As part of the Continuing Planning Process, DEQ staff presented the EPA-approved TMDLs to the State Water Control Board (SWCB) for inclusion in the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning.

DEQ staff also requested that the SWCB adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9 VAC 25-720). This regulatory action is in accordance with §2.2-4006A.14 and §2.2-4006B of the Code of Virginia. SWCB actions relating to water quality management planning are described in the public participation guidelines referenced above and also available on DEQ's website here: [Guidance for Public Participation Procedures for Water Quality Management Planning](#).

Following the EPA approval and SWCB adoption of this TMDL, DEQ may develop an implementation plan. The implementation plan development will incorporate local stakeholders from agriculture, business, governmental sectors, and local communities to discuss feasible and attainable steps needed to meet the goals set in this TMDL. The implementation plan aims to select the most locally adoptable and cost-effective best management practices (BMPs) to reduce non-point sources and meet the load allocations described in the TMDL. DEQ TMDL staff will seek EPA and SWCB approval of the implementation plan following development.

## 7.2 Implementation of Waste Load Allocations and Reasonable Assurances

Federal regulations require that all new or revised National Pollutant Discharge Elimination System (NPDES) permits are consistent with the assumptions and requirements of any applicable TMDL WLA (40 CFR §122.44 (d)(1)(vii)(B)). EPA will review all such permits.

For the implementation of the WLA component of the TMDL, DEQ utilizes the Virginia Pollutant Discharge Elimination System (VPDES) program and the Virginia Stormwater Management Program (VSMP). The TMDL process should not duplicate requirements of the permit process. Depending on the type and nature of a point source discharge, a TMDL implementation plan may inform it, or the discharge permit may address it solely through provisions. Overall, implementation plan development may help to coordinate the efforts of permitted stormwater sources through the collaborative process involved in development of the plan. Stormwater permittees will be strongly encouraged to participate in the development of TMDL implementation plans since recommendations from the process may contribute to updates to the stormwater management plan in order to meet the TMDLs.

### 7.2.1 Stormwater Permits

DEQ regulates stormwater discharges associated with industrial activities through its VPDES program and regulates stormwater discharges from construction sites and municipal separate storm sewer systems (MS4s) through the VSMP. While housed in different regulations, permits allowing the discharge of industrial stormwater, construction stormwater, and stormwater from MS4s are all administered through VPDES permits. As with non-stormwater permits, all new or revised stormwater permits must stay consistent with the assumptions and requirements of any applicable TMDL WLA.

### 7.2.2 Existing Non-Stormwater VPDES Permits

The discharge concentration limits serve as an effective surrogate to demonstrate that VPDES individual and general domestic permittees are meeting established bacteria wasteload allocations. Direct measurement and evaluation of concentration end-points, whether established as effluent limits or benchmark concentrations, is the expected method for demonstrating permitted discharges are consistent with the assumptions and requirements of this TMDL.

### 7.2.3 TMDL Modifications for New or Expanding Discharges

Permits issued for facilities with WLAs developed as part of a TMDL must stay consistent with the assumptions and requirements of these WLAs, per EPA regulations. In cases where a new permit or proposed permit modification occurs in a TMDL watershed and is therefore affected by a TMDL WLA, permit and TMDL staff will coordinate to ensure that new or expanding discharges meet this requirement. In 2014, DEQ issued Guidance Memorandum No. 14-2015 describing the available options and the process that should be followed under those circumstances, including public participation, EPA approval, State Water Control Board actions, and coordination between permit and TMDL staff. The guidance memorandum is available on DEQ's website here: [DEQ Website for Guidance Memorandum No. 14-2015](#).

## 7.3 Implementation of Load Allocation and Reasonable Assurance

Once EPA approves a TMDL, states must take measures to reduce pollution levels from both point and nonpoint sources. EPA requires that there is reasonable assurance for implementation of TMDLs. TMDLs represent an attempt to identify the pollutant load that is present in a waterbody and quantify the reductions needed in pollutant loads for attainment and maintenance of water quality standards. The Commonwealth intends to use existing programs in order to attain water quality goals by implementing BMPs, enforcing existing regulations, and continuing to monitor water quality.

The following sections outline the framework used in the Commonwealth of Virginia to provide reasonable assurance that the required pollutant reductions are achieved.

### 7.3.1 Implementation of Load Allocations

The TMDL program does not impart new implementation authorities for load allocations. Therefore, the Commonwealth intends to use existing programs to the fullest extent in order to attain its water quality goals. TMDL partners implement measures for nonpoint source reductions in an iterative process that is described along with specific BMPs in the TMDL implementation plan. These measures can include the use of better treatment technology and the installation of BMPs.

### 7.3.2 Implementation Plan Development

For the implementation of the TMDL's LA component, DEQ, with the help of interested partners and local stakeholders, will develop a TMDL implementation plan that addresses at a minimum the requirements specified in the Code of Virginia, Section 62.1-44.19:7. State law directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters". The implementation plan "shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments". EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process". The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards (USEPA, 1999a).

In order to qualify for other funding sources, such as EPA's Section 319 grants, additional plan requirements may need to be met. The DEQ "TMDL Implementation Plan Guidance Manual" was published in July 2017 and describes the detailed process for developing an implementation plan. It is available upon request from the VADEQ TMDL project staff or here:

[DEQ Website for the TMDL Implementation Plan Guidance Manual](#)

Watershed stakeholders will have opportunities to provide input and to participate in the development of the TMDL implementation plan. Regional and local offices of VADEQ and other cooperating agencies are technical resources to assist in this endeavor.

With successful completion of implementation plans, local stakeholders will have a blueprint to restore impaired waters and enhance the value of their land and water resources. Additionally, an approved implementation plan may enhance opportunities for stakeholders to obtain financial and technical assistance during implementation.

### 7.3.3 Staged Implementation Scenarios

The purpose of the staged implementation scenarios is to identify one or more combinations of implementation actions that result in the reduction of controllable sources to the maximum extent practicable using cost-effective, reasonable BMPs for nonpoint source control. Among the most

efficient bacterial BMPs are stream-side fencing for cattle, pet waste clean-up programs, and government or grant programs available to homeowners for failing septic systems or installation of treatment systems to replace straight pipes.

DEQ expects that implementation of the bacteria TMDLs will occur in stages, and that full implementation of the TMDLs is a long-term goal. Project coordinators and partners will develop specific goals for staged implementation as part of implementation plan development. The iterative implementation of pollution control actions in the watershed has several benefits:

1. Enables tracking of water quality improvements following implementation through follow-up stream monitoring.
2. Provides a measure of quality control, given the uncertainties inherent in TMDL development.
3. Provides a mechanism for developing public support through periodic updates on implementation levels and water quality improvements.
4. Ensures that the first practices implemented are the most cost effective.
5. Evaluates the adequacy of the TMDL in achieving water quality standards.

Many BMPs that address bacteria also address potential benthic stressors like sediment, hydromodification, and habitat modification. For example, an improvement in stormwater management is one method for decreasing bacteria but will also result in reduced sediment entering urban streams. DEQ will recommend bacteria measures that also address other impairments as priority BMPs.

#### 7.3.4 [Link to Ongoing Restoration Efforts](#)

Implementation of this TMDL report will contribute to on-going water quality improvement efforts aimed at restoring water quality in the project area. The project falls within the Chesapeake Bay area. As such the Chesapeake Bay TMDL and Implementation Plan will also contribute to water quality improvement efforts (VADEQ, 2018b).

#### 7.3.5 [Implementation Funding Sources](#)

Implementation of pollutant reductions from non-regulated nonpoint sources relies heavily on incentive-based programs. Therefore, it is key that project partners identify funding sources for non-regulated implementation activities. Cooperating agencies, organizations and stakeholders

must identify potential funding sources available for implementation during the development of the implementation plan in accordance with the "Guidance Manual for Total Maximum Daily Load Implementation Plans". The TMDL Implementation Plan Guidance Manual contains information on a variety of funding sources, as well as agencies, foundations and nonprofit organizations that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

Some of the major potential sources of funding may include the U.S. Department of Agriculture's Conservation Reserve Enhancement- and Environmental Quality Incentive Programs, EPA Section 319 funds, the Virginia State Revolving Loan Program (also available for permitted activities), the Virginia Water Quality Improvement Fund (available for both point and nonpoint source pollution), tax credits and landowner contributions.

The Water Quality Improvement Fund (WQIF) has become a significant funding source for agricultural BMPs and wastewater treatment plants. Additionally, funding is being made available to address urban and residential water quality problems. Information on WQIF projects and allocations can be found here:

[DEQ Website for the Water Quality Improvement Fund](#)

#### 7.3.6 Follow-Up Monitoring

Following the development of the TMDL, DEQ will continue to monitor the impaired watersheds in accordance with its ambient monitoring program. VADEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. A lag time is possible between when BMPs are established and when ambient water samples reflect these changes. DEQ staff, in cooperation with local stakeholders, will determine the purpose, location, parameters, frequency, and duration of the monitoring. Each DEQ Regional Office will include the details of the follow-up monitoring in their Annual Water Monitoring Plan. Other agency personnel, stakeholders, etc. may provide input on the Annual Water Monitoring Plan. These recommendations must be made to the DEQ regional TMDL coordinator each year.

Monitoring efforts will continue following completion of a TMDL implementation plan. DEQ staff, in cooperation with the Implementation Plan Steering Committee (if active) and other local

stakeholders, will continue to use data from the ambient monitoring stations to evaluate the water quality milestones established in the implementation plan, the effectiveness of the TMDL in attaining and maintaining water quality standards, and the success of implementation efforts. Participants can then recommend targeting implementation efforts in specific areas and continuing or discontinuing monitoring at follow-up stations. Grant-funded projects are an option local stakeholders can pursue if levels are close to the water quality standards.

In some cases, watersheds will require monitoring above and beyond what is included in DEQ's standard monitoring plan. Supplementary monitoring by local government, citizens' or watershed groups, local government, or universities is an option for such cases. Supplementary monitoring should follow established Quality Assurance and Quality Control (QA/QC) guidelines in order to maximize compatibility with DEQ monitoring data. In instances where citizens' monitoring data is not available and additional monitoring is needed to assess the effectiveness of targeting efforts, regional TMDL staff may request of the monitoring managers in each regional office an increase in the number of stations or to monitor existing stations at a higher frequency in the watershed. Additional monitoring beyond the original bimonthly single station monitoring is contingent on staff resources and available laboratory budget. More information on citizen monitoring in Virginia and QA/QC guidelines is available here: [DEQ Website for Citizen Water Quality Monitoring](#)

To demonstrate that the impaired waterbody is meeting water quality standards after corrective actions have taken place, DEQ must meet the minimum data requirements from the original listing stations or a station representative of the originally listed station.

#### 7.4 Attainability of Designated Uses

The goal of a TMDL is to restore impaired waters to attain water quality standards. Water quality standards consist of statements that describe water quality requirements and include three components: 1) designated uses, 2) water quality criteria to protect designated uses, and 3) an antidegradation policy. Implementing cost-effective and reasonable best management practices to reduce bacteria (*E. coli*) loads to the maximum extent practicable will ultimately result in attaining bacteria TMDLs. However, for some streams with developed TMDLs, factors may prevent the stream from attaining its designated use. The state must remove the current designated use in order to give a stream a new designated use, a subcategory of a use, or a tiered

use. To remove a designated use, the state must demonstrate that the use is not an existing use, and that downstream uses are protected.

The state must also demonstrate that attaining the designated use is not feasible because of one or more of the following reasons:

1. Naturally occurring pollutant concentration prevents the attainment of the use.
2. Natural, ephemeral, intermittent, or low flow conditions prevent the attainment of the use unless these conditions are compensated for by the discharge of sufficient volume of pollutant discharges without violating state water conservation.
3. Human-caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place.
4. Dams, diversions, or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the waterbody to its original condition or to operate the modification in such a way that would result in the attainment of the use.
5. Physical conditions related to natural features of the waterbody, such as the lack of proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life use protection.
6. Controls more stringent than those required by §301b and §306 of the Clean Water Act would result in substantial and widespread economic and social impact.

This and other information is collected through a special study called a Use Attainability Analysis (UAA). The SWCB must adopt all site-specific criteria or designated use changes as amendments to the water quality standards regulations. During the regulatory process, stakeholders and other interested citizens, as well as the EPA, are able to provide comment.

The process to address potentially unattainable reductions based on the above is as follows:

As a first step, implementation will focus on measures targeted at the controllable, anthropogenic sources of all pollutants and non-pollutants causing or contributing to the impairment. In addition, TMDL and permit staff will ensure discharge permits are fully implementing provisions required in the TMDL. The expectation is for the reductions of all controllable sources to be to the maximum extent practicable. DEQ will continue to monitor water quality in

the impaired streams during and after the implementation of these measures to determine if water quality standards are attained. This effort will also help to evaluate if the modeling assumptions used in the TMDL were correct. In the best-case scenario, the stream will meet water quality goals and have its uses fully restored using pollution controls and BMPs. If, however, water quality standards are not met, and there are no identifiable additional pollution controls and BMPs, staff may initiate a UAA with the goal of re-designating the stream for a more appropriate use, subcategory of a use, or tiered use.

A 2006 amendment to the Code of Virginia under 62.1-44.19:7E provides an opportunity for aggrieved parties in the TMDL process to present to the State Water Control Board reasonable grounds indicating that the attainment of the designated use for a water is not feasible. The Board may then allow the aggrieved party to conduct a use attainability analysis prior to TMDL development according to the criteria listed above and a schedule established by the Board. The amendment further states that “If applicable, the schedule shall also address whether TMDL development or implementation for the water shall be delayed.”

## 8 PUBLIC PARTICIPATION

DEQ staff encouraged public participation during TMDL development for the Mattaponi River and Tributaries study area. A summary of the meetings is presented in Table 8-1, with paragraph summaries following. There were a total of two public meetings and three technical advisory committee (TAC) meetings.

*Table 8-1. Public participation during TMDL development for the study area*

Meeting (Date)	Location	Organizations in Attendance	Number of Attendees	Purpose
1st TAC Meeting (10/03/2018)	King and Queen Branch Library, St. Stephens Church, VA	DEQ, VIMS, Streams Tech, Three Rivers SWCD, King William County, Caroline County	11	Introduce the TMDL process, present local stream impairments, and solicit comments from the stakeholders. Discuss potential local sources of bacteria.
1st Public Meeting (10/15/2018)	King and Queen Branch Library, St. Stephens Church, VA	DEQ, Virginia Tech BSE, Local Soil and Water Conservation Districts (SWCD), Northern Neck PDC, VDH, Natural Resource Conservation Service	11	Introduce the TMDL to stakeholders. Receive feedback about outreach strategies. Identify areas for collaboration. Initiate discussions about local land use.
2nd TAC Meeting (05/08/2019)	King and Queen Branch Library, St. Stephens Church, VA	DEQ, VIMS, Streams Tech, King William County, King and Queen County, VADOC, VDH, King and Queen Fish Hatchery, Caroline County	17	Review the project and TMDL process with stakeholders and discuss the source assessment.
3rd TAC Meeting (06/26/2019)	King and Queen Branch Library, St. Stephens Church, VA	DEQ, VIMS, Streams Tech, VADOC, VDGIF (VDWR), local residents	11	Review the project and TMDL process with stakeholders and discuss the draft loadings and allocations.
Final Public Meeting (12/09/2020)	Virtual Meeting			

**TAC Meeting No. 1:** DEQ held an initial TAC meeting on October 3, 2018, at the King and Queen Branch Library in St. Stephens Church, VA, in advance of the first Public Meeting. Five stakeholders from local governments and the local Soil and Water Conservation District and four representatives from DEQ, Streams Tech, Inc., and the Virginia Institute of Marine Sciences (VIMS) attended this meeting. The purpose of the meeting was to introduce the TMDL process to the technical stakeholders, receive feedback about outreach strategies, identify areas for

collaboration, and initiate discussions about local land uses. The DEQ TMDL Coordinator announced the meeting via email and on the VA Town Hall website.

**Public Meeting No. 1:** DEQ held the first public meeting on October 15, 2018, at the King and Queen Branch Library in St. Stephens Church, VA. Eleven people attended the meeting, including one stakeholder from the Virginia Department of Transportation (VDOT), six local residents, and four representatives from DEQ, Streams Tech, Inc., and VIMS. DEQ introduced the TMDL process, presented local stream impairments, and solicited comments from the stakeholders. The group also discussed potential local sources of bacteria. A public comment period followed the meeting (10/16/2018-11/14/2018). Persons interested in reviewing project materials through an advisory committee were invited to notify the DEQ contact person. The DEQ TMDL Coordinator announced the meeting via email, local fliers, newspaper ads, and on the VA Town Hall and Registers websites.

**TAC Meeting No. 2:** DEQ held a second TAC meeting on May 8, 2019, at the King and Queen Branch Library in St. Stephens Church, VA. Seventeen people attended the meeting, including eight stakeholders from local agencies and the local Soil and Water Conservation District, four local residents, and five representatives from DEQ, Streams Tech, Inc., and VIMS. The purpose of the meeting was to review the project and TMDL process with stakeholders and to discuss the source assessment. The DEQ TMDL Coordinator announced the meeting via email and on the VA Town Hall website.

**TAC Meeting No. 3:** DEQ held a third TAC meeting on June 26, 2019, at the King and Queen Branch Library in St. Stephens Church, VA. Eleven people attended the meeting. The purpose of the meeting was to review the project and TMDL process with stakeholders and to discuss the draft loadings and allocations. The DEQ TMDL Coordinator announced the meeting via email and on the VA Town Hall website.

**Public Meeting No. 2:** A second and final public meeting was held...

## 9 REFERENCES

---

American Society of Agricultural Engineers Standards (ASAE), 45th Edition. 1998. D384.1 DEC93. Manure Production and Characteristics. St. Joseph, Mich.

American Veterinary Medical Association (AVMA). 2012. U.S. Pet Ownership Statistics. Available at: [Website for the American Veterinary Medical Association U.S. Pet Ownership Statistics](#)

Bicknell, B.R., J.C. Imhoff, J. Kittle, A.S. Donigian, and R.C. Johansen. 1996. Hydrological Simulation Program - FORTRAN, Users Manual for Release H. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Ga.

Bicknell, B.R., J.C. Imhoff, J.L. Kittle, Jr., T.H. Jobes, A.S. Donigian, Jr. 2005. *HSPF Version 12.2 User's Manual*. Mountain View, CA: AQUA TERRA Consultants. In Cooperation with the U.S. Geological Survey and U.S. Environmental Protection Agency. 845 pp.

Duda, P., J. Kittle, Jr., M. Gray, P. Hummel, R. Dusenbury. 2001. WinHSPF, Version 2.0, An Interactive Windows Interface to HSPF, User Manual. Contract No. 68-C-98-010. USEPA. Washington D.C. pp. 95.

Geldreich, E.E. 1978. Bacterial populations and indicator concepts in feces, sewage, stormwater and solid wastes. In *Indicators of Viruses in Water and Food*, ed. G. Berg, ch. 4, 51-97. Ann Arbor, Mich.: Ann Arbor Science Publishers, Inc.

Hamrick, J. M. 1992. A three-dimensional environmental fluid dynamics computer code: Theoretical and computational aspects. Special Report in Applied Marine Science and Ocean Engineering. No. 317. The College of William and Mary, VIMS, 63 pp.

Homer, C.G., Dewitz, J.A., Yang, L., Jin, S., Danielson, P., Xian, G., Coulston, J., Herold, N.D., Wickham, J.D., and Megown, K., 2015, Completion of the 2011 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information. *Photogrammetric Engineering and Remote Sensing*, v. 81, no. 5, p. 345-354.

Humane Society of the United States (HSUS). 2012. Pets By The Numbers. Available at: [Humane Society of the United States Website for Pets By The Numbers](#)

Hyer K.E. and Moyer D. L. 2003. Patterns and sources of fecal coliform bacteria in three streams in Virginia 1999 2000 US Geological Survey Water Resources Investigations Report 03 4115.

Lumb and Kittle, 1993. Users Manual for an Expert System (HSPEXP) for Calibration of the Hydrological Simulation Program-Fortran. U.S. Geological Survey, Virginia.

MapTech, Inc. 2000. Fecal Coliform TMDL (Total Maximum Daily Load) Development for South Fork of the Blackwater River, Virginia. Washington, D.C.: USEPA.

MRLC. National Land Cover Database. 2011. Available at: [2011 National Land Cover Database Website](#)

National Climatic Data Center (NCDC). 2019. National Oceanic and Atmospheric Administration: National Climatic Data Center. Available at: [NOAA website for National Climatic Data](#)

Park, K., Kuo, A. Y., Shen, J., and Hamrick, J. M. 1995. A Three-dimensional Hydrodynamic Eutrophication Model (HEM-3D): Description of Water Quality and Sediment Process Submodels. Special Report in Applied Marine Sci. and Ocean Engin. No. 327, pp. 102, Virginia Institute of Marine Sci., Gloucester Point, VA 23062.

Rice, K.C., Bennett, M.R., and Shen, Jian, 2011, Simulated changes in salinity in the York and Chickahominy Rivers from projected sea-level rise in Chesapeake Bay: U.S. Geological Survey Open-File Report 2011–1191, 31 p. Available at: <https://pubs.usgs.gov/of/2011/1191/pdf/ofr20111191.pdf>

Shen, J., Perry, J., Wang, R., Sisson, M. 2017. Change of salinity in the Pamunkey River due to withdrawal. A Report submitted to ARCADIS U.S., Inc.

Shen, J., A. Parker, and J. Riverson. 2005. A new approach for a windows-based watershed modeling system based on a database-supporting architecture. Environmental modeling and software 20: 1127-1138.

Staley, N.A., T. Bright, R.W. Zeckoski, B.L. Benham, and K.M. Brannan. 2006. Comparison of HSPF Outputs Using FTABLES Generated with Field Survey and Digital Data. *J. of the Am. Water Res. Assoc.* In Press.

State Water Control Board (SWCB). 2019. 9 VAC 25-260 Virginia Water Quality Standards. Available at: [Website for Virginia Water Quality Standards](#)

U.S. Census Bureau. 1990. 1990 U.S. Census Data for Virginia.

U.S. Census Bureau. 2010. 2010 U.S. Census Data for Virginia.

U.S. Department of Agriculture, National Agricultural Statistics Service (USDA-NASS). 2013. Virginia Cropland Data Layer. Available at: [USDA Website for National Agricultural Statistics Service Research and Science](#)

U.S. Department of Agriculture, National Agricultural Statistics Service (USDA-NRCS) 2015. Official Soil Series Descriptions (OSD). Available at: [USDA Official Soil Series Descriptions \(OSD\) Website](#).

U.S. Department of Agriculture, National Agricultural Statistics Service (USDA-NRCS) 2019. State Soil Geographic Data (SSURGO) Soils Data. Available at: [USDA NRCS State Soil Geographic Data \(SSURGO\) Soils Data Website](#)

U.S. Department of Agriculture. 2012. Census of Agriculture. Available at [USDA 2012 Census of Agriculture Website](#)

U.S. Environmental Protection Agency (EPA). 1985. Rates, Constants, and Kinetics formulations in Surface Water Quality Modeling. Athens, GA.

U.S. Environmental Protection Agency (USEPA). 1999a. Guidance for Water Quality-Based Decisions: The TMDL Process.

U.S. Environmental Protection Agency (USEPA). 1999b. Level III And IV Ecoregions Of Delaware, Maryland, Pennsylvania, Virginia, and West Virginia.

U.S. Environmental Protection Agency (USEPA). 2001. EPA 841-R-00-002. Protocols for developing Pathogen TMDLs.

U.S. Environmental Protection Agency (USEPA). 2007. OWOW 2007 Options for Expressing Daily Loads in TMDLs, Office of Wetland, Ocean & Watersheds, Washington, DC.

U.S. Geological Survey (USGS). 2016 National Elevation Dataset (NED) 1 arc-second Downloadable Data Collection from The National Map 3D Elevation Program (3DEP) - National Geospatial Data Asset (NGDA) National Elevation Data Set (NED): U.S. Geological Survey.

U.S. Geological Survey (USGS). 2018. Virginia National Watershed Boundary Dataset Version 5. Available at: [VA DCR Website for Hydrologic Unit Geography](#)

U.S. Geological Survey (USGS). 2019. National Water Information System. Available at: [http://waterdata.usgs.gov/nwis/inventory?search\\_criteria=search\\_site\\_no&submitted\\_form=introduction](http://waterdata.usgs.gov/nwis/inventory?search_criteria=search_site_no&submitted_form=introduction)

Virginia Department Environmental Quality (VADEQ). 2003. Guidance Memo No. 03-2012. HSPF Model Calibration and Verification for Bacteria TMDLs. Memo from Larry G. Lawson to Regional Directors. September 3, 2003.

Virginia Department of Environmental Quality (VADEQ). 2011. Final 2010 305(B)/303(D) Water Quality Assessment Integrated Report.

Virginia Department of Environmental Quality (VADEQ). 2012. Total Maximum Daily Loads of DO and Pathogens for Gargathy Creek (-Upper, -Lower, and Riverine Portions) in Accomack County, Virginia.

Virginia Department of Environmental Quality (VADEQ). 2013. Final 2012 305(B)/303(D) Water Quality Assessment Integrated Report.

Virginia Department of Environmental Quality (VADEQ). 2014. *E. coli* TMDL Development for the Pamunkey River and Tributaries, VA.

Virginia Department of Environmental Quality (VADEQ). 2016a. 2016 Contractor Recommendations.

Virginia Department of Environmental Quality (VADEQ). 2016b. Final 2014 305(B)/303(D) Water Quality Assessment Integrated Report.

Virginia Department of Environmental Quality (VADEQ). 2018a. 2016 305(b)/303(d) Water Quality Assessment Integrated Report. Available at: [VADEQ Website for Final 2016 305\(b\)/303\(d\) Water Quality Assessment Integrated Report](#). LINK WILL BE UPDATED ONCE WEBSITE IS UPDATED

Virginia Department of Environmental Quality (VADEQ). 2018b. Chesapeake Bay TMDL. Available at: [VADEQ Website for the Chesapeake Bay TMDL](#). LINK WILL BE UPDATED ONCE WEBSITE IS UPDATED

Virginia Department of Environmental Quality (VADEQ). 2019. 2018 305(b)/303(d) Water Quality Assessment Integrated Report. Available at: [VADEQ Website for Final 2018 305\(b\)/303\(d\) Water Quality Assessment Integrated Report](#). LINK WILL BE UPDATED ONCE WEBSITE IS UPDATED

Virginia Department of Environmental Quality (VADEQ). 2020. 2020 305(b)/303(d) Water Quality Assessment Integrated Report. Available at: [VADEQ Website for Final 2020 305\(b\)/303\(d\) Water Quality Assessment Integrated Report](#). LINK WILL BE UPDATED ONCE WEBSITE IS UPDATED

Virginia Department of Game and Inland Fisheries (VDGIF), 2015. Virginia Fish and Wildlife Information Service. <[www.dgif.virginia.gov](http://www.dgif.virginia.gov)>.

Virginia Tech. 2000. Fecal Coliform TMDL for Sheep Creek, Elk Creek, Machine Creek, Little Otter River, and Lower Big Otter River in Bedford and Campbell Counties, Virginia. Department of Biological Systems Engineering, Virginia Tech. December, 2000.

Weiskel, P.A., B.L. Howes, and G.R. Heufelder. 1996. Coliform contamination of a coastal embayment: sources and transport pathways. *Environ. Sci. Technol.* 30: 1872-1881.

Yagow, G. 2001. Fecal Coliform TMDL: Mountain Run Watershed, Culpeper County, Virginia.  
Available at: [Mountain Run Fecal Coliform TMDL](#).

DRAFT

## Appendix A: Glossary

---

### Water Quality

1. Anthropogenic
  - a. Influenced by human activities.
2. Assessment Unit
  - a. Segment of a waterbody delineated to categorize water quality and attainment of designated uses, based on the National Hydrography Dataset (NHD)
3. Bacteria
  - a. Single-celled microorganisms. Bacteria from the coliform group are considered the main indicators of fecal pollution and are often used to evaluate water quality.
4. Bacteria Source Assessment
  - a. A data gathering process to identify potential sources of fecal pollution, using methods such as sanitary surveys, watershed tours, locality data, etc.
5. Cause
  - a. That which produces an effect (a general definition).
  - b. The source of the defined impairment of a waterbody, i.e. bacteria.
6. Channel
  - a. A natural stream that carries water, or a ditch or channel excavated for the flow of water.
7. Confluence
  - a. The point at which a waterway and its tributary flow together.
8. Contamination
  - a. The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.
9. Conveyance
  - a. A measure of the transportation rate of water within a channel section. It is directly proportional to the discharge of the channel section.
10. Cross-sectional area
  - a. Wet area of a waterbody that is perpendicular to the longitudinal component of the flow.

11. MGD

- a. Million gallons per day. A unit of water flow rate, whether discharge or withdraw.

12. Monitoring

- a. Periodic or continuous surveillance or testing to determine pollutant levels in air, water, humans, plants and animals. It can also determine the level of compliance with statutory requirements.

13. Narrative criteria

- a. Qualitative guidelines that describe a desired water quality goal or goals.

14. Natural waters

- a. Flowing water within a physical system that has developed without human involvement, in which natural processes continue to take place.

15. Nonpoint source

- a. Combined pollution that originates from various sources over a relatively large area and cannot be traced to a direct source. Nonpoint sources can be divided into source activities related to either land or water use including failing septic systems, improper animal-keeping practices, forest practices, and urban and rural runoff.

16. Numeric targets

- a. A measurable goal value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the impaired water body.

17. Parameter

- a. Water characteristics that are measured through monitoring and studied during assessments (DO, pH, bacteria, etc.).

18. Pathogen

- a. Disease-causing microorganisms such as bacteria, protozoa, and viruses.

19. Point source

- a. Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

20. Pollutant

- a. Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).

21. Pollution

- a. Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

22. Reach

- a. Segment of a stream or river.

23. Receiving waters

- a. Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.

24. Runoff

- a. Precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can pick up and carry pollutants from the air and land into receiving waters.

25. Source

- a. An origination point, area, or entity that releases or emits a stressor. A source can alter the normal intensity, frequency, or duration of a natural attribute, whereby the attribute then becomes a stressor.

40. Surface area

- a. The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.

41. Surface runoff

- a. Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.

42. Surface water

- a. All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.

43. Topography

- a. The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features

44. Total Maximum Daily Load (TMDL)

- a. The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). It is the maximum amount of a pollutant that can enter a waterbody while still reaching water quality standards. TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

45. Transport of pollutants (in water)

- a. Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.

46. Tributary

- a. A lower order-stream compared to a receiving water body. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.

47. Urban Runoff

- a. Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

48. Wastewater

- a. Usually refers to effluent from a sewage treatment plant. See also Domestic wastewater.

49. Wastewater treatment

- a. Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.

50. Water quality

- a. The biological, chemical, and physical conditions of a waterbody. It is a measure of a water body's ability to support beneficial uses.

51. Water quality criteria

- a. Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.

52. Water quality standard

- a. Law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body, and an antidegradation statement.

53. Watershed

- a. A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Regulations/Policies

54. 303(d)

- a. A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the State's water quality standards.

55. Allocation(s)

- a. That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources.

56. Clean Water Act (CWA)

- a. The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C.

1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is section 303(d), which establishes the TMDL program.

57. Future Growth

- a. Pollutant loading rate set aside in determining stream waste load allocation, accounting for uncertainty and infrastructure or economic expansions.

58. National Pollutant Discharge Elimination System (NPDES)

- a. Program established by the Clean Water Act that regulates the amount of pollutants municipal and industrial point sources may discharge into surface waters of the United States.

59. Permit

- a. An authorization, license, or equivalent control document issued by the EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.

60. Phased/staged approach

- a. Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.

61. Public comment period

- a. The time allowed for the public to express its views and concerns regarding action by EPA or states, typically 30 days (e.g., a Federal Register notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).

62. Septic system

- a. An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a drain field or subsurface absorption system consisting of a series of

percolation lines to dispose of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.

63. Sewer

- a. A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.

64. Stakeholder

- a. Any person with a vested interest in the TMDL development process.

65. Straight pipe

- a. Delivers wastewater directly from a building (e.g., house, milking parlor) to a stream, pond, lake, or river.

66. Waste load allocation (WLA)

- a. The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).

67. Water quality-based permit

- a. A permit with an effluent limit more stringent than one based on technology performance. Such limits might be necessary to protect the designated use of receiving waters (e.g., recreation, irrigation, industry, or water supply).

## Implementation Approaches

1. Best Management Practices (BMPs)

- a. Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

2. Restoration

- a. Return of an ecosystem to a close approximation of its presumed original condition prior to disturbance.

### 3. Staged Implementation

- a. A process that allows for the evaluation of the adequacy of the TMDL in achieving the water quality standard. As stream monitoring continues to occur, staged or phased implementation allows for water quality improvements to be recorded as they are being achieved. It also provides a measure of quality control, and it helps to ensure that the most cost-effective practices are implemented first.

### 4. Stream restoration

- a. Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.

### 5. TMDL Implementation Plan

- a. A document required by Virginia statute detailing the suite of pollution control measures needed to remediate an impaired waterbody. The plans are also required to include a schedule of actions, costs, and monitoring. Once implemented, the plan should result in the previously impaired water meeting water quality standards and achieving a "fully supporting" use support status.

## Modelling

### 1. Calibration

- a. The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

### 2. Critical condition

- a. The critical condition can be thought of as the "worst case" scenario of environmental conditions in the water body in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.

### 3. Model

- a. Mathematical representation of hydrologic and water quality processes. Effects of land use, slope, soil characteristics, and management practices are included.

4. PERLND

- a. A pervious land segment in HSPF. It is used to model a particular land use segment within a subwatershed (e.g. pasture, urban land, or crop land).

5. Simulation

- a. The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.

6. Slope

- a. The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).

7. Statistical threshold value

- a. Approximates the 90<sup>th</sup> percentile of water quality distribution

8. Validation (of a model)

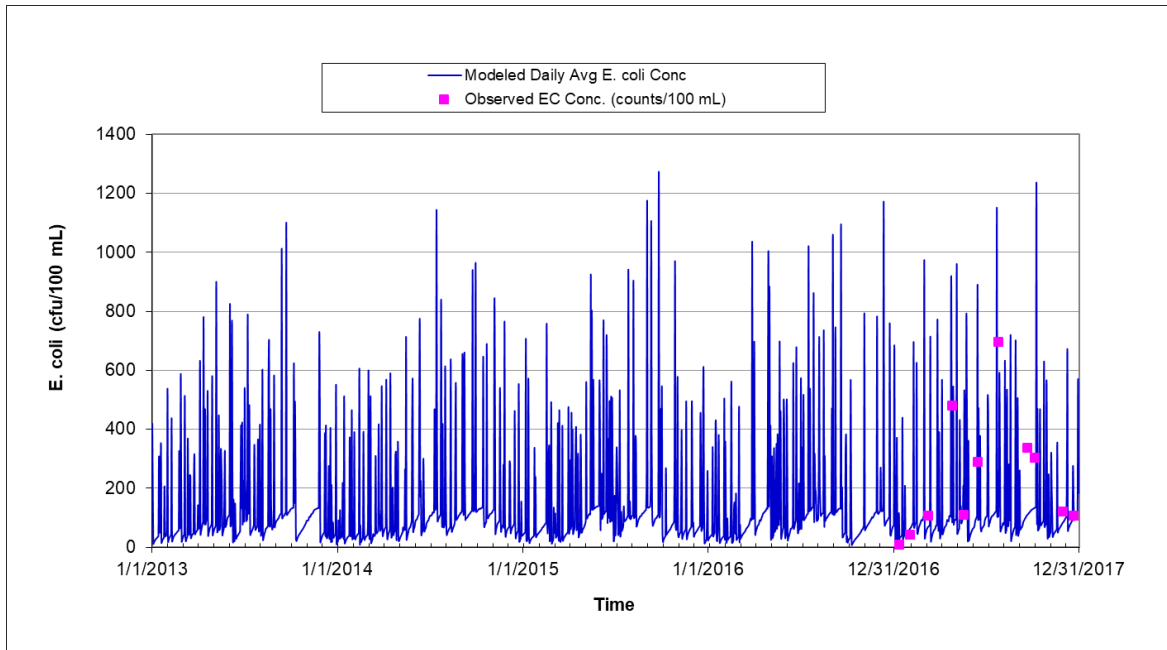
- a. Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical processes under investigation. A validated model will have also been tested to ascertain whether it accurately and correctly solves the equations being used to define the system simulation.

## Appendix B: Inventory of data and information used in TMDL development

Data Category	Description	Source(s)
Watershed physiographic data	Watershed boundary	USGS National Hydrography Dataset version 4
Watershed physiographic data	Land use/land cover	Homer (2015)
Watershed physiographic data	Soil data (Soil Data Mart)	USDA-NRCS (2013)
Watershed physiographic data	Topographic data (National Elevation Dataset (NED) 1 arc-second)	USGS 2016
Hydrographic data	Stream network and reaches (1:24k resolution) - National Hydrography Dataset	USGS (2008)
Weather data	Information, data, reports, and maps that can be used to support fecal coliform source identification and loading	NCDC (2015)
Watershed activities & bacteria sources	Livestock inventory	Census of Agriculture (2012)
Watershed activities & bacteria sources	Wildlife inventory	Mattaponi River Watershed Bacteria TMDL (2016), VDGIF (2015)
Watershed activities & bacteria sources	Septic systems inventory and failure rates	Mattaponi River Watershed Bacteria TMDL (2016), Census Bureau (1990, 2010)
Watershed activities & bacteria sources	Pet estimates	AVMA (2012)
Point sources and direct discharge data and information	Permitted facilities locations and discharge monitoring reports (DMRs)	VADEQ
Environmental monitoring data	Monitoring data (bacteria) and station locations	VADEQ
Environmental monitoring data	Stream flow data	USGS (2016)

## Appendix C: Time Series Plots for Water Quality Calibration and Validation

---



*Figure C-1. Aylett Creek Water Quality Calibration (2013-2017) Results at Station 8-AYL002.27*

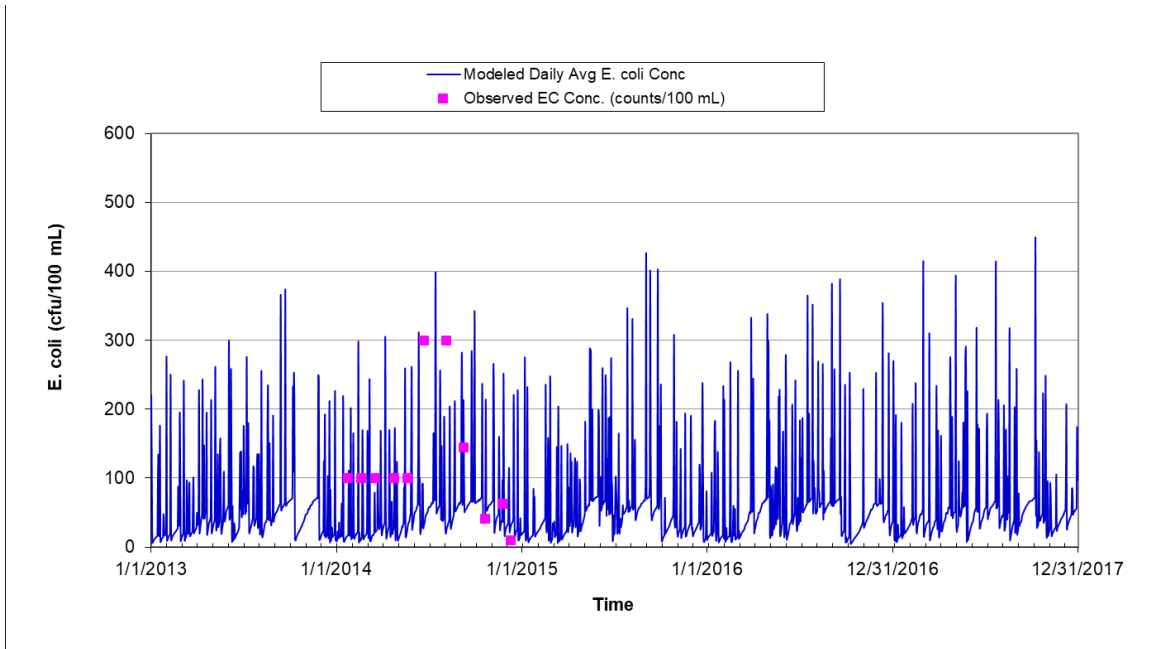


Figure C-2. Courthouse Creek Water Quality Calibration (2013-2017) Results at Station 8-CTH001.96

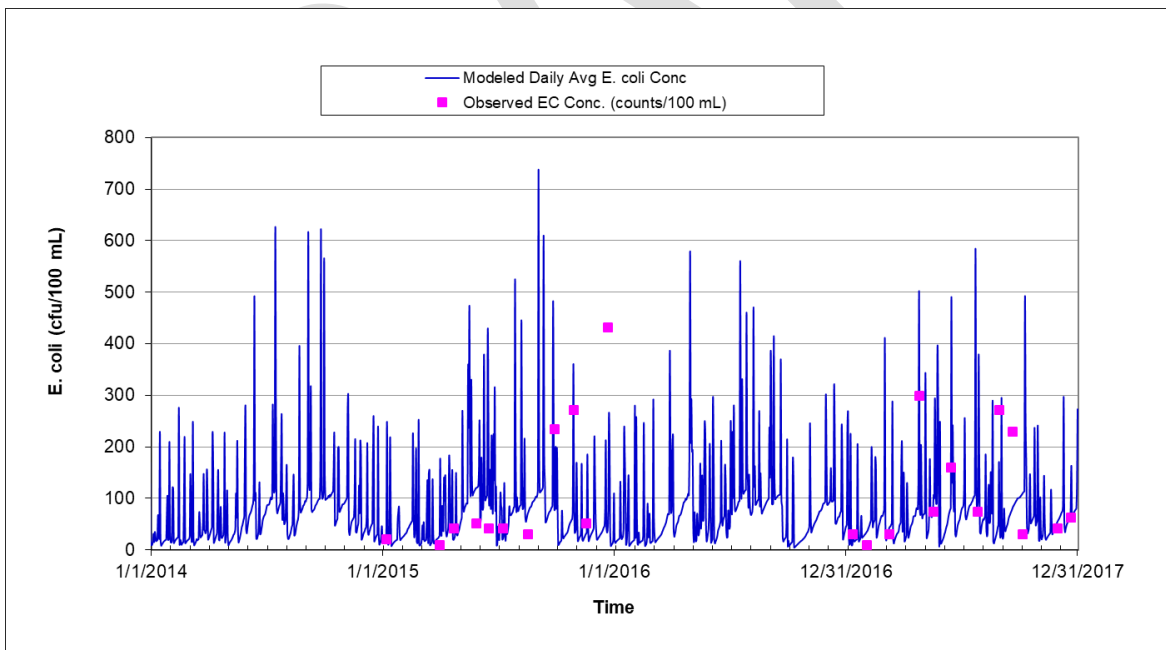
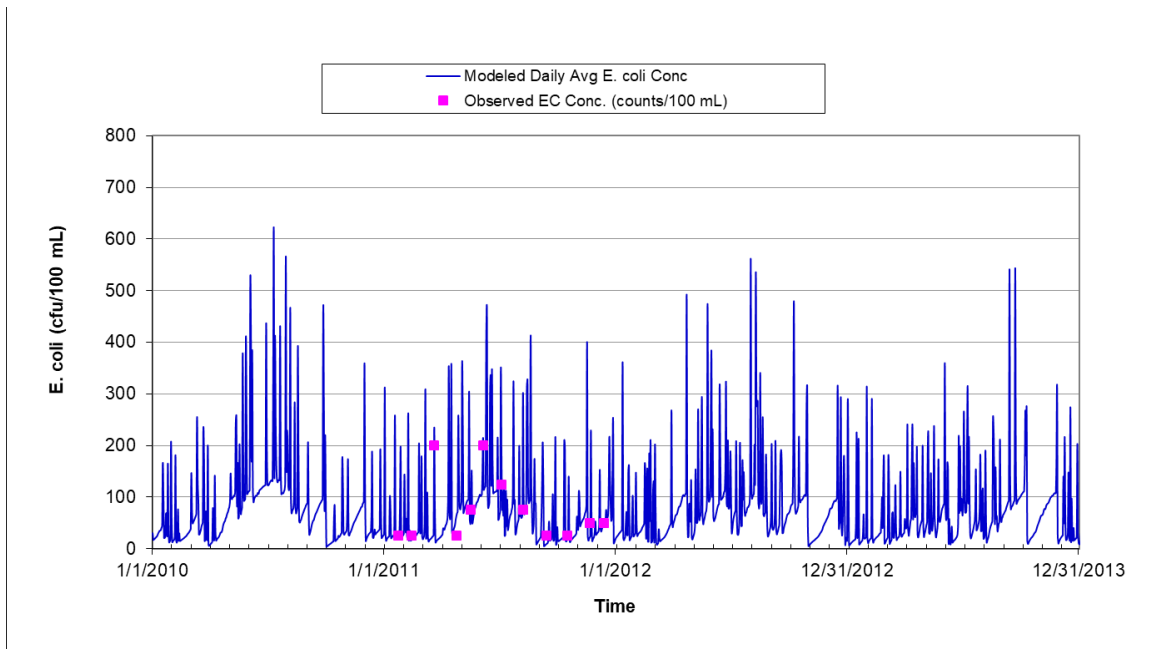
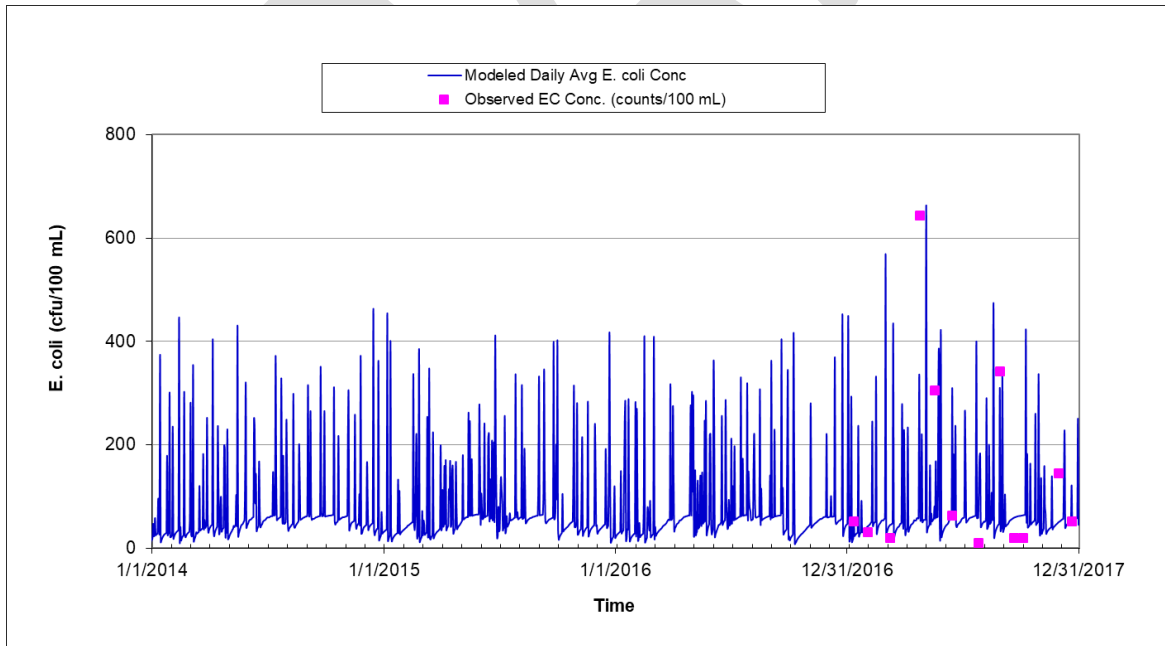


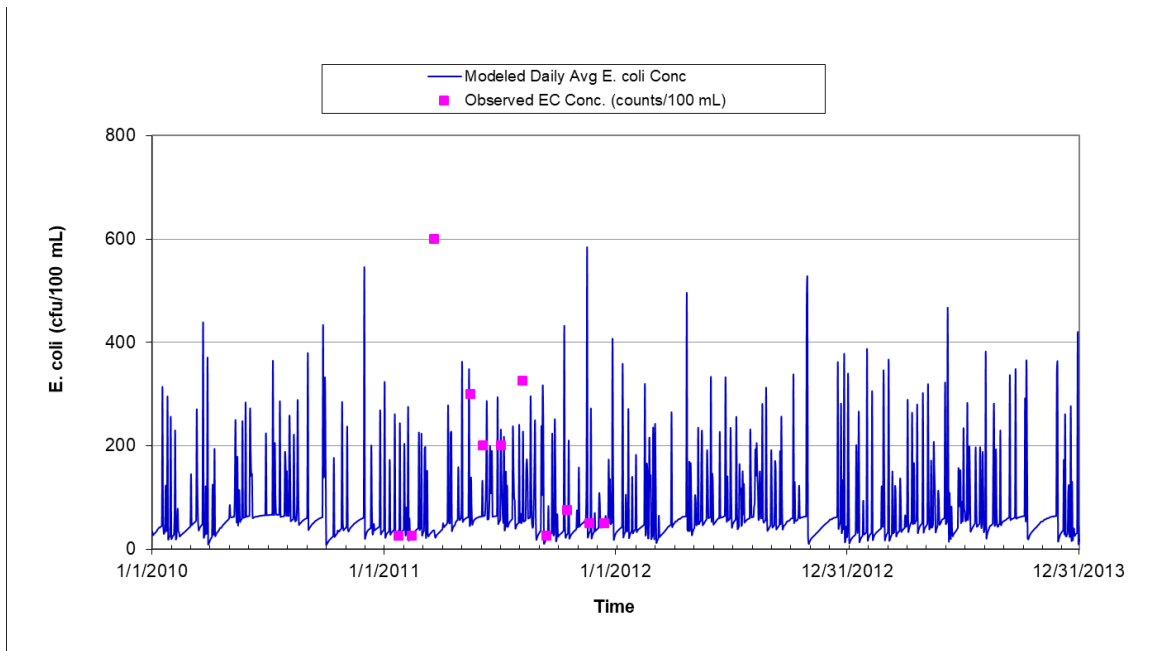
Figure C-3. Dickey's Swamp Water Quality Calibration (2014-2017) Results at Station 8-DKW000.12



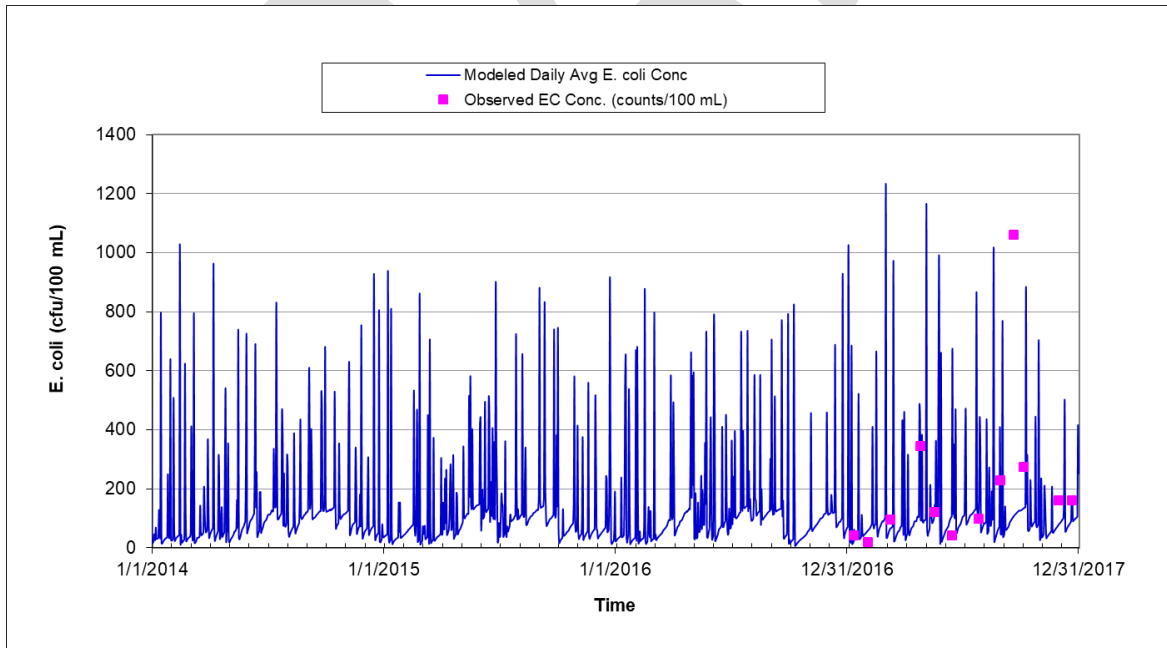
*Figure C-4. Dickey's Swamp Water Quality Validation (2010-2013) Results at Station 8-DKW000.12*



*Figure C-5. Dogwood Fork Water Quality Calibration (2014-2017) Results at Station 8-DWD000.77*



*Figure C-6. Dogwood Fork Water Quality Validation (2010-2013) Results at Station 8-DWD000.77*



*Figure C-7. Garnetts Creek Water Quality Calibration (2014-2017) Results at Station 8-GNT001.54*

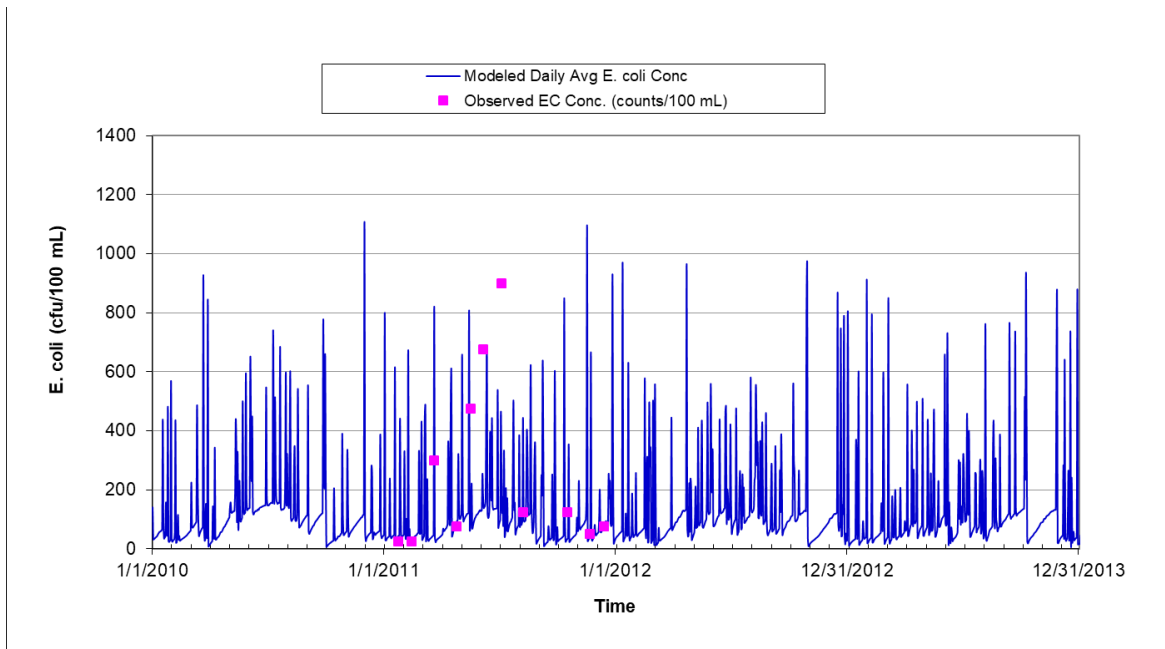


Figure C-8. Garnetts Creek Water Quality Validation (2010-2013) Results at Station 8-GNT001.54

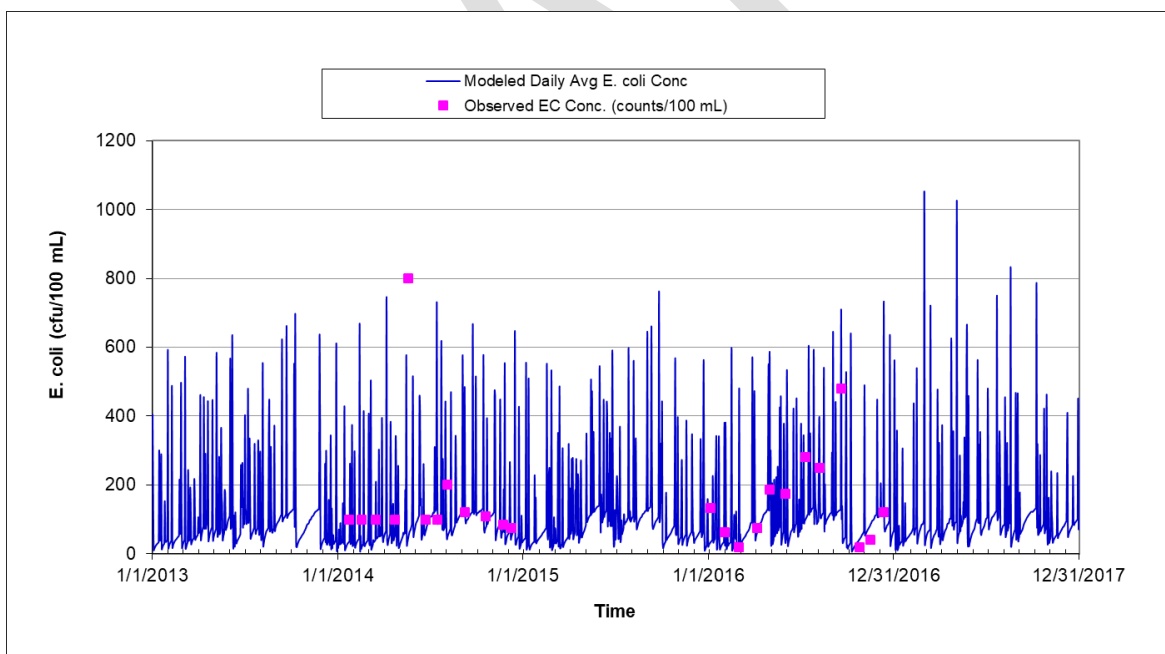


Figure C-9. Herring Creek Water Quality Calibration (2013-2017) Results at Station 8-HER000.33

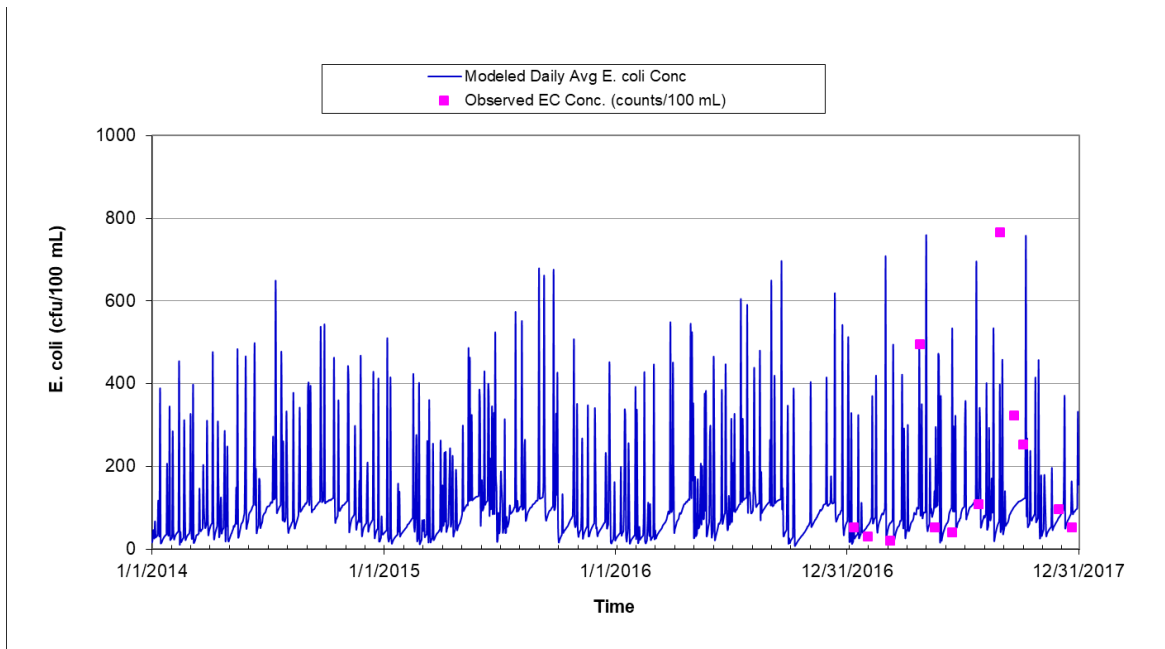


Figure C-10. Market Swamp Water Quality Calibration (2014-2017) Results at Station 8-MKT001.04

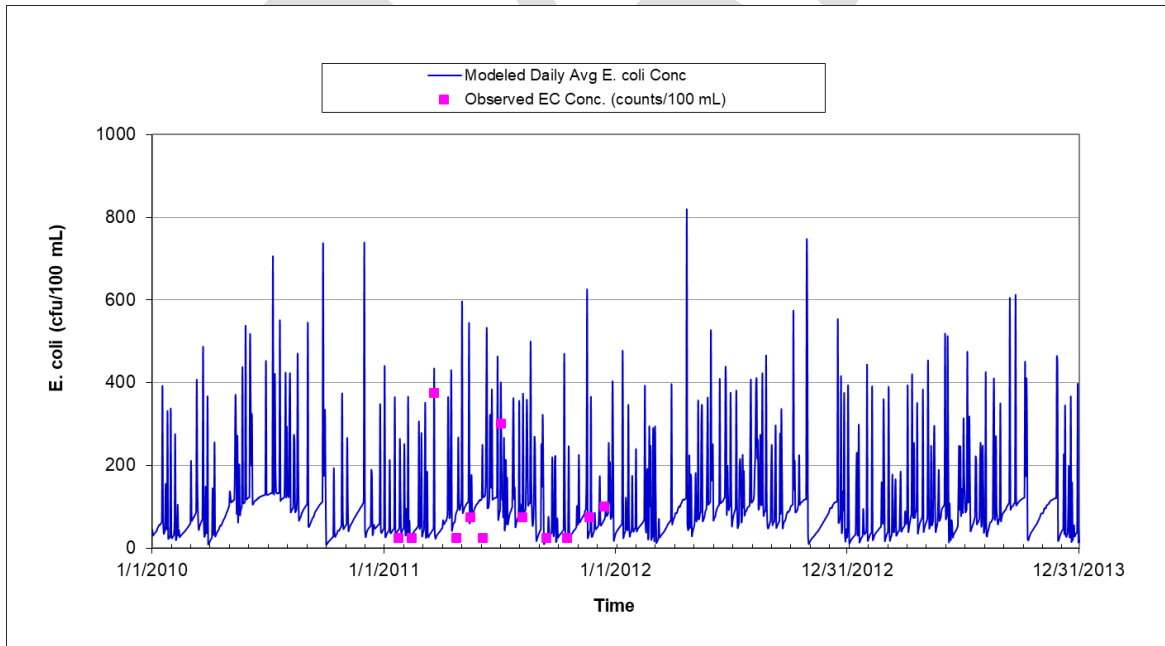


Figure C-11. Market Swamp Water Quality Validation (2010-2013) Results at Station 8-MKT001.04

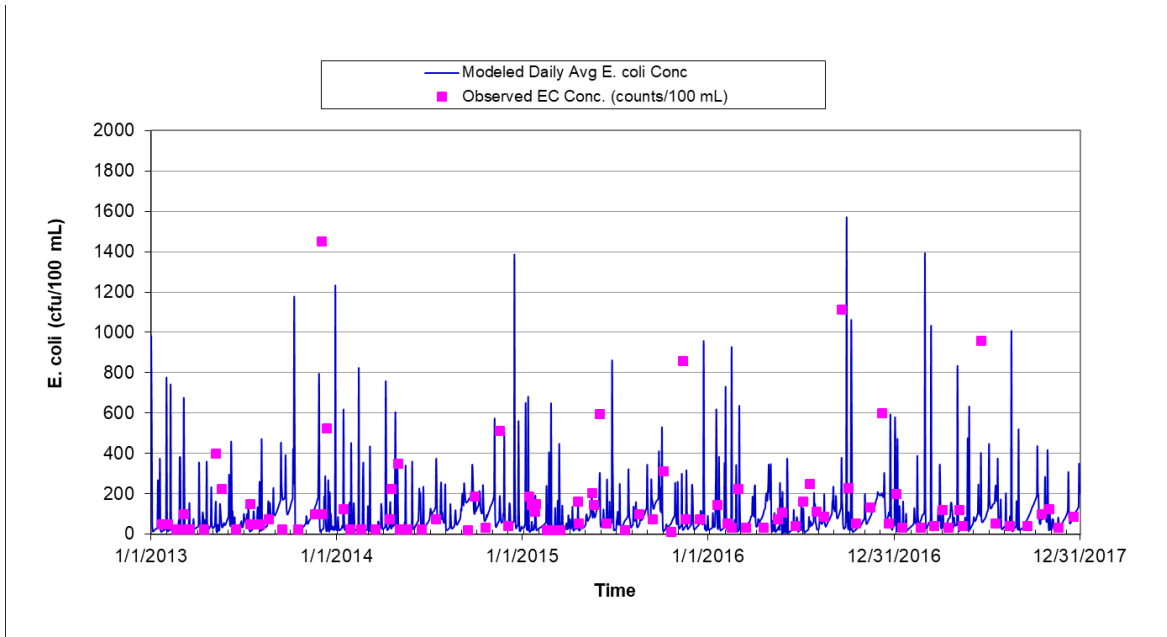


Figure C-12. Mattaponi River (Tidal) Water Quality Calibration (2013-2017) Results at Station 8-MPN083.62

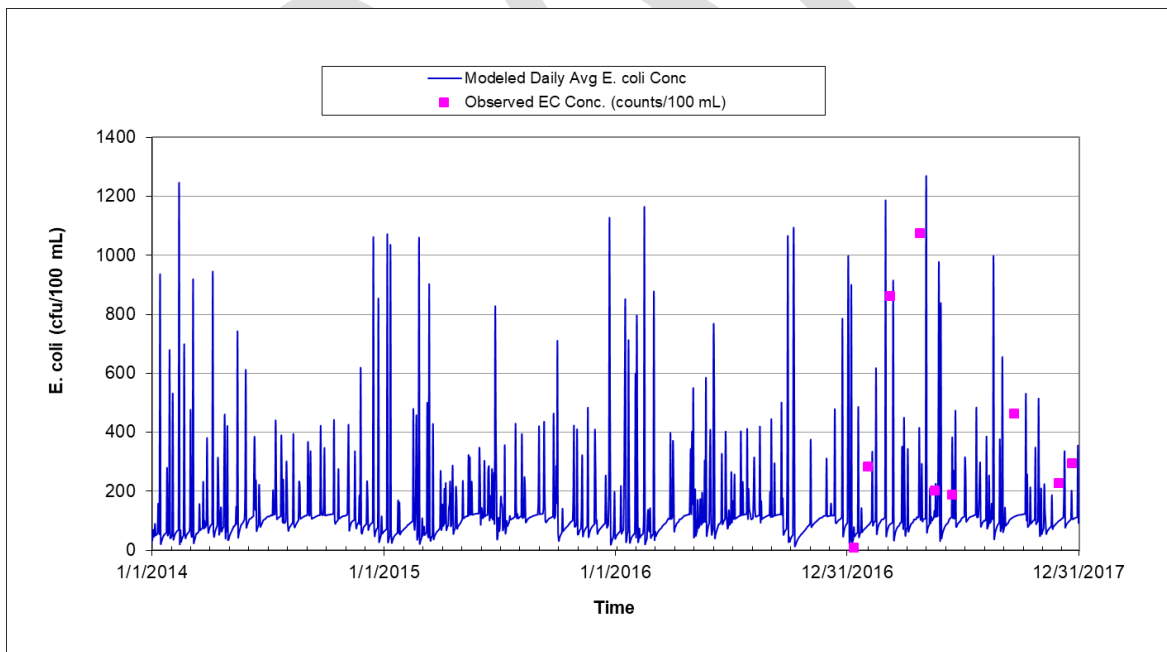


Figure C-13. XDN-Garnetts Creek, UT Water Quality Calibration (2014-2017) Results at Station 8-XDN000.12

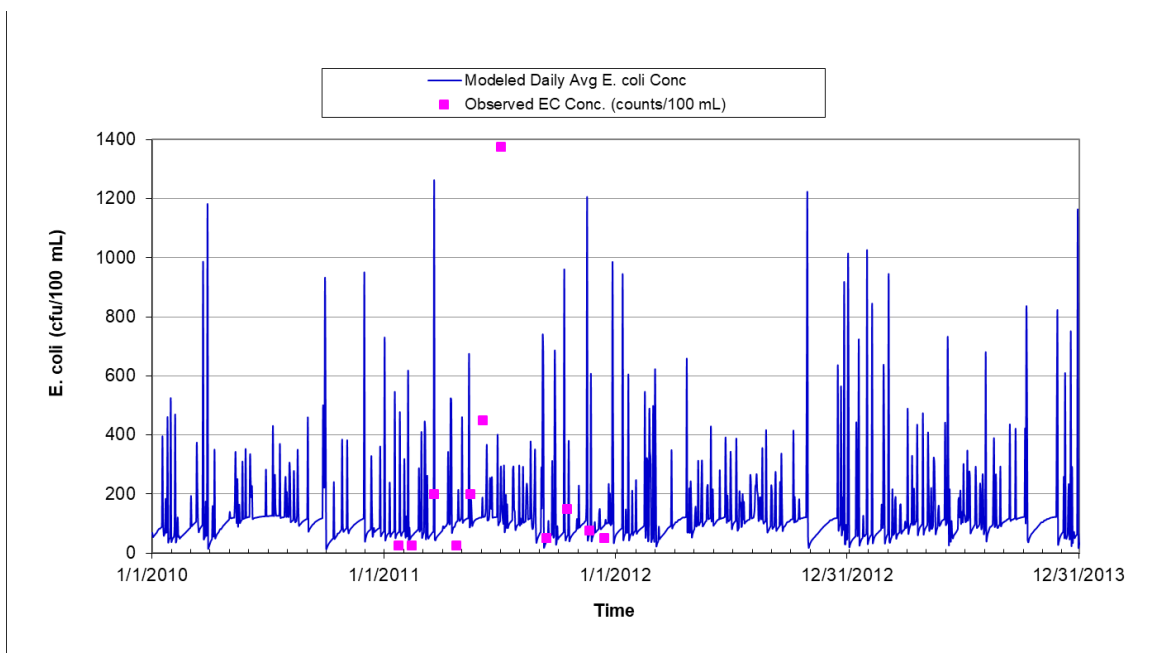


Figure C-14. XDN-Garnetts Creek, UT Water Quality Validation (2010-2013) Results at Station 8-XDN000.12

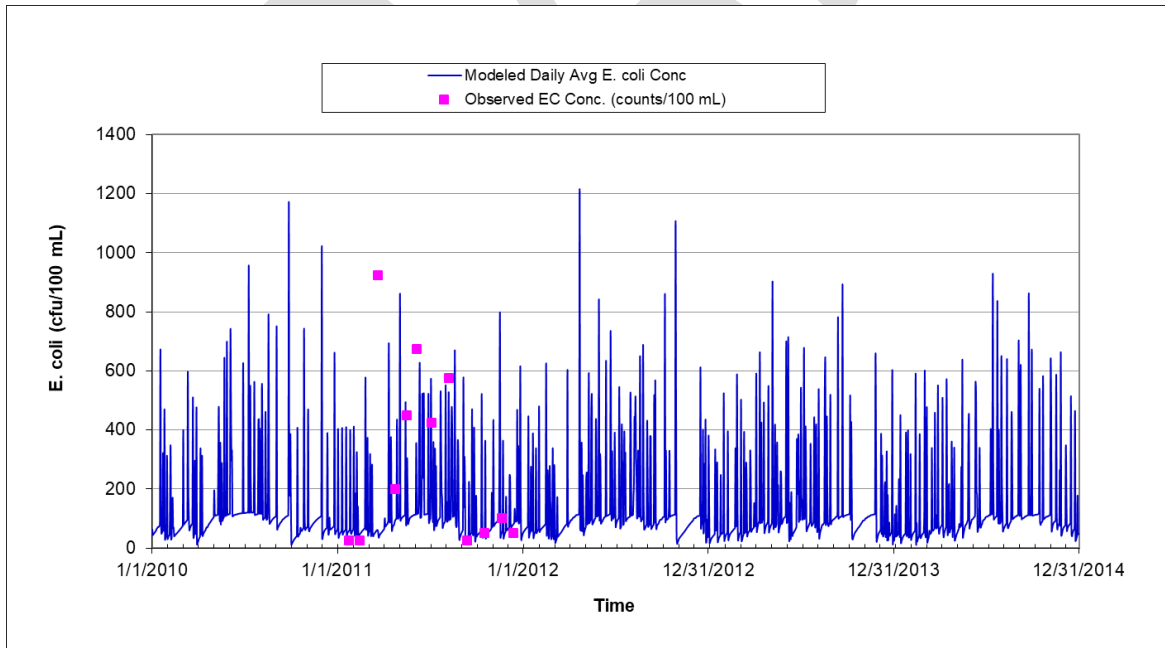
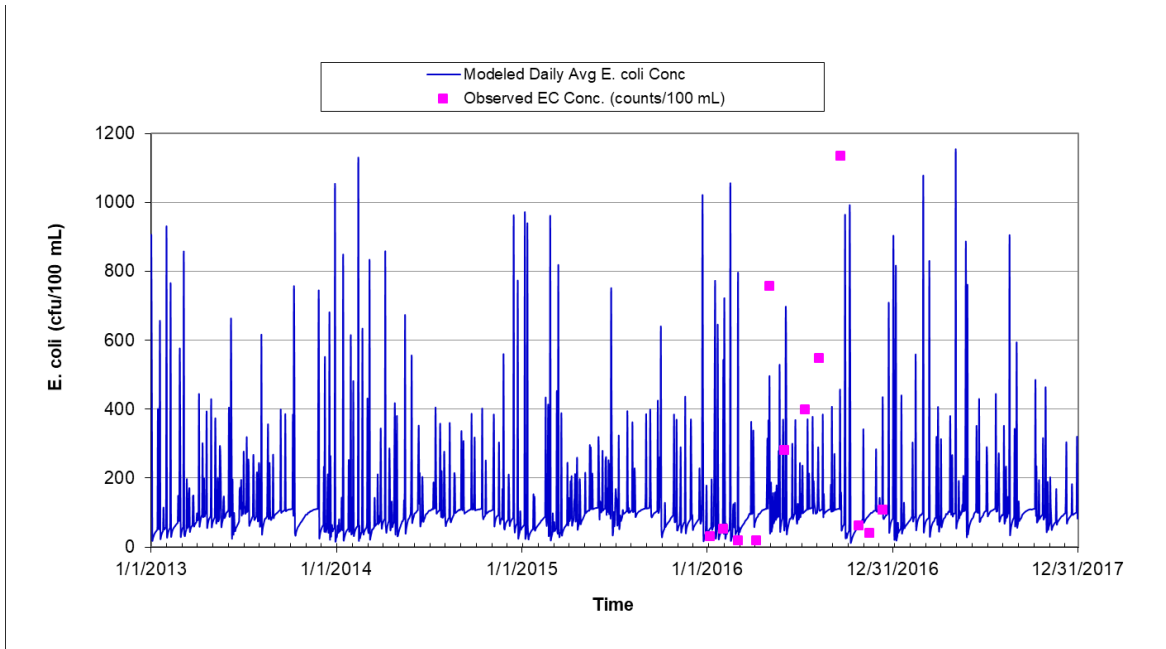
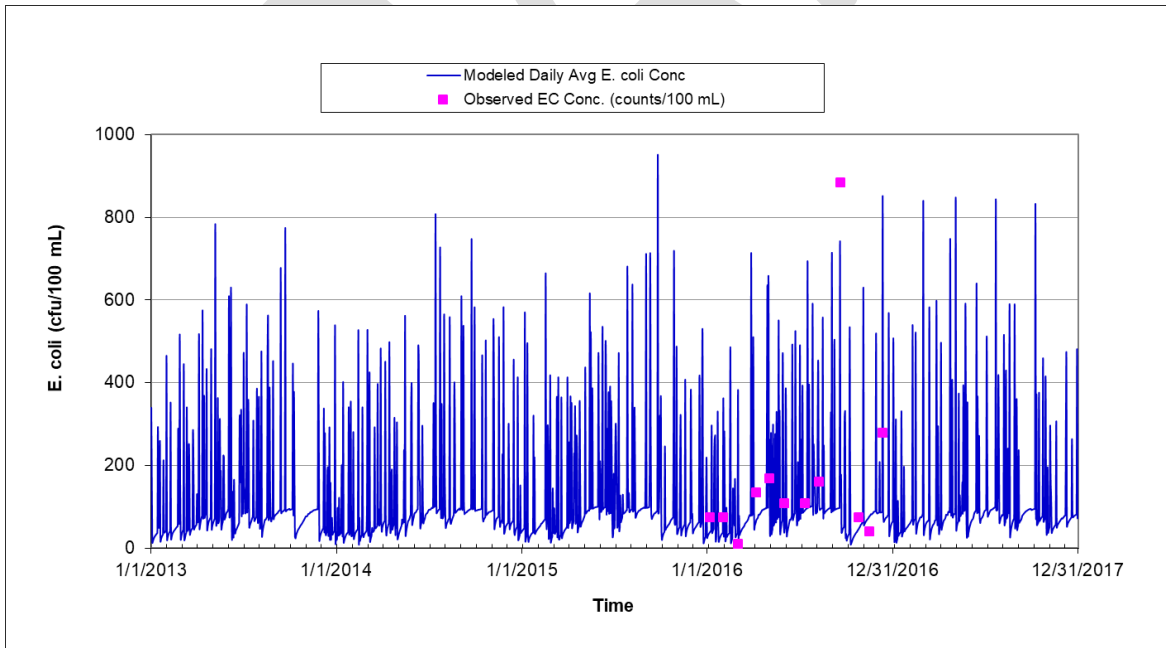


Figure C-15. XJG-Dickeys Swamp, UT Water Quality Calibration (2013-2017) Results at Station 8-XDN000.12



*Figure C-16. Gravel Run Water Quality Calibration (2013-2017) Results at Station 8-GVL000.56*



*Figure C-17. Dorrell Creek Water Quality Calibration (2013-2017) Results at Station 8-DRL000.85*

## Appendix D: HSPF Model Sensitivity Analysis

---

Many parameters in the HSPF models cannot be directly measured or precisely estimated during model development. Past studies and literature may have recommended ranges depending on various conditions. Some of the parameters directly affect the hydrologic and hydraulic modeling results, while other parameters affect the water quality results. The complex and non-linear relationships between input and output in the HPSF model require that a sensitivity analysis be performed to evaluate the impact of changes in parameter values on the model response. Sensitivity analysis involves changing one parameter at a time by a certain percentage of the calibrated value, running the simulation and comparing the model results. This process is repeated for each of the selected parameters and summarized to show the potential effects of uncertainty in parameter estimation. Sensitivity analyses, as discussed in the next sections, were conducted to assess the impacts of changes in hydrologic as well as water quality parameters.

### Hydrology Sensitivity Analysis

In developing a hydrologic model the parameters that control the total flow volume, runoff and low flow are of significant interest, especially in the context of estimating bacteria loads. LZSN (Lower Zone Nominal Storage), LZETP (lower zone evapotranspiration), INTERCEP (interception) and BASETP (baseflow evapotranspiration) are the most important parameters in determining the evapotranspiration loss and thus simulating the total volume of flow. In addition to the input data describing the physical characteristics of the land surface, INFILT (infiltration) and UZSN (upper zone storage) control the surface runoff during storm events. AGWRC (active groundwater recession coefficient), DEEPER (groundwater Inflow to deep recharge) and KVARV (groundwater recession parameter) are the important parameters that govern the low flow. Parameters that determine the total volume of flow also have significant impact on low flow under dry weather conditions.

The HSPF parameters adjusted for the hydrologic sensitivity analysis along with the calibrated values are presented below. The parameters were adjusted to -50%, -10%, +10%, and +50% of the calibrated values, and the model was run for the period from January 1, 2013 to December 31, 2017. Where an increase or decrease of 50% exceeded the possible ranges of values for a parameter, the maximum and/or minimum value was used and the parameter values used in the

sensitivity analysis were reported. As shown in Table D-2, a comparison of the model sensitivity results indicates that INTERCEP and UZSN are the most sensitive parameters, and LZETP and INTFW are the least sensitive parameters. Decreasing INTERCEP by 50% causes increases in summer storm volume by 8.32% and the lowest 50% flows by 4.168%.

*Table D-1. HSPF Parameters for Sensitivity Analysis*

Parameter	Description	Units	Base Value
LZSN	Lower Zone Nominal Storage	in	6-6.5
INFILT	Soil Infiltration Capacity	in/hr	0.01-0.11
BASETP	Base Flow Evapotranspiration	-	0.02-0.04
INTFW	Interflow Inflow	-	1.1-1.6
DEEPER	Groundwater Inflow to Deep Recharge	-	0.05
AGWRC	Groundwater Recession rate	-	0.92
KVARY	Groundwater Recession Flow	1/in	0
MON-INTERCEP	Monthly Interception Storage Capacity	in	0.1-0.35
UZSN	Monthly Upper Zone Nominal Storage	in	0.7-0.8
MON-LZETP	Monthly Lower Zone Evapotranspiration	in	0.005-0.1

The model responses due to the sensitization of the hydrologic model parameters are shown below.

*Table D-2. Percent Change of Model Hydrologic Parameters*

Model Parameter	Parameter Change (%) or Adjusted Value	Total Runoff	Total of highest 10% flows Percent Change	Total of Lowest 50% Flows Percent Change	Winter Flow Volume Percent Change	Summer Storm Volume Percent Change
AGWRC	0.87	0.15%	1.88%	-2.277%	0.44%	0.31%
AGWRC	0.91	0.04%	0.30%	-0.764%	0.13%	0.06%
AGWRC	0.93	-0.04%	-0.45%	0.531%	-0.17%	-0.04%
AGWRC	0.97	-0.31%	-2.52%	2.010%	-1.84%	0.50%
BASETP	-50	0.44%	0.39%	0.929%	0.00%	1.92%
BASETP	-10	0.08%	0.02%	0.021%	0.00%	0.33%
BASETP	10	-0.07%	-0.02%	-0.357%	0.00%	-0.30%
BASETP	50	-0.32%	-0.16%	-0.855%	0.00%	-1.30%
DEEPFR	-50	0.36%	0.33%	0.531%	0.33%	0.47%
DEEPFR	-10	0.07%	0.07%	0.106%	0.07%	0.09%
DEEPFR	10	-0.07%	-0.07%	-0.106%	-0.07%	-0.09%

Model Parameter	Parameter Change (%) or Adjusted Value	Total Runoff	Total of highest 10% flows Percent Change	Total of Lowest 50% Flows Percent Change	Winter Flow Volume Percent Change	Summer Storm Volume Percent Change
DEEPPFR	50	-0.36%	-0.33%	-0.531%	-0.33%	-0.47%
INFILT	-50	-0.41%	1.09%	-2.100%	0.68%	-3.20%
INFILT	-10	-0.09%	-0.17%	-0.433%	0.11%	-0.59%
INFILT	10	0.09%	0.29%	0.064%	-0.10%	0.58%
INFILT	50	0.46%	0.51%	1.684%	-0.46%	2.80%
INTFW	-50	-0.13%	-0.34%	0.067%	0.05%	-0.41%
INTFW	-10	-0.02%	-0.39%	-0.001%	0.01%	-0.06%
INTFW	10	0.02%	0.03%	0.049%	-0.01%	0.06%
INTFW	50	0.06%	-0.54%	-0.052%	-0.02%	0.22%
LZSN	-50	1.06%	3.67%	-1.686%	2.18%	-1.30%
LZSN	-10	0.27%	0.29%	-0.067%	0.45%	0.03%
LZSN	10	-0.27%	-0.06%	-0.162%	-0.45%	-0.05%
LZSN	50	-1.39%	-1.81%	-0.969%	-2.22%	-0.49%
INTERCEP	-50	2.70%	1.48%	4.168%	0.55%	8.32%
INTERCEP	-10	0.45%	0.29%	0.518%	0.10%	1.34%
INTERCEP	10	-0.39%	-0.22%	-0.660%	-0.08%	-1.17%
INTERCEP	50	-1.79%	-0.83%	-3.292%	-0.40%	-5.61%
LZETP	-50	0.26%	1.56%	-0.077%	0.57%	-0.36%
LZETP	-10	0.06%	-0.07%	0.080%	0.12%	-0.05%
LZETP	10	-0.07%	0.04%	-0.001%	-0.13%	0.05%
LZETP	50	-0.38%	-0.17%	-0.309%	-0.66%	0.20%
KVARY	0	0.00%	0.00%	0.000%	0.00%	0.00%
KVARY	3	0.29%	3.74%	-3.948%	0.95%	0.64%
UZSN	-50	3.39%	2.85%	4.001%	2.03%	6.88%
UZSN	-10	0.51%	0.70%	0.342%	0.38%	0.88%
UZSN	10	-0.45%	-0.24%	-0.459%	-0.38%	-0.74%
UZSN	50	-1.87%	-1.63%	-1.057%	-1.86%	-2.57%

## Water Quality Parameter Sensitivity Analysis

Following the sensitivity analysis of the hydrologic parameters, a sensitivity analysis of the water quality parameters in HSPF was performed using the input data for the period from 2013 through 2017. Bacteria is modeled in HSPF as a general quality constituent. The corresponding modules for pervious and impervious lands and stream reaches involve three calibration parameters, which are the maximum accumulation limit (MON-SQOLIM), wash-off

rate on land surface (WSQOP) and in-stream first order decay rate (FSTDEC), impacting the model's water quality response. These three HSPF parameters were increased and decreased by amounts that were consistent with the range of values for the parameter. The calibrated values and units of water quality parameters are presented in Table D-3. Tables D-4 through D-15 show the results of parameter sensitivity analysis for each of the 12 impaired watersheds. Generally the parameter values are more sensitive to a reduction of parameter value than an increase of value. However, the most sensitive parameter varies from one watershed to another. WSQOP shows the most sensitivity in Courthouse Creek, Dickey's Swamp, Dogwood Fork, Dorrell Creek, Garnetts Creek, Gravel Run, Market Swamp, Mattaponi River (non-tidal), XDN-Garnetts Creek, UT and XJG-Dickey's Swamp, UT in the winter months, whereas FSTDEC shows the most sensitivity in Aylett Creek and Herring Creek in the summer months. MON-SQOLIM is generally the least sensitive parameter and it shows the lowest sensitivities in July or August.

*Table D-3. Sensitivity Analysis Parameters for Water Quality*

Parameter	Description	Units	Base Value
MON-SQOLIM	Maximum FC Accumulation on Land	FC/ac	1.7E+07 - 8.8E+10
WSQOP	Wash-off Rate for FC on Land Surface	in/hr	0.45-2.8
FSTDEC	In-stream First Order Decay Rate	1/day	1.152

Table D-4. Percent Change in *E. coli* Geometric Mean concentrations for 2008-2012 at the outlet of Aylett Creek

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly <i>E. coli</i> Geometric Mean											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FSTDEC	-50	3.29%	3.80%	4.88%	5.75%	7.26%	9.83%	9.00%	8.07%	4.97%	4.05%	3.44%	3.09%
FSTDEC	-10	0.64%	0.74%	0.94%	1.10%	1.37%	1.82%	1.67%	1.51%	0.95%	0.78%	0.67%	0.60%
FSTDEC	10	-0.63%	-0.73%	-0.93%	-1.07%	-1.33%	-1.77%	-1.61%	-1.46%	-0.93%	-0.77%	-0.66%	-0.59%
FSTDEC	50	-3.12%	-3.56%	-4.50%	-5.19%	-6.37%	-8.32%	-7.59%	-6.94%	-4.46%	-3.74%	-3.22%	-2.91%
MON-SQOLIM	-50	-1.67%	-1.43%	-1.13%	-0.54%	-0.97%	-0.73%	-0.13%	-0.20%	-0.29%	-0.39%	-0.31%	-1.10%
MON-SQOLIM	-10	-0.33%	-0.29%	-0.23%	-0.11%	-0.20%	-0.15%	-0.03%	-0.04%	-0.06%	-0.08%	-0.06%	-0.22%
MON-SQOLIM	10	0.32%	0.28%	0.22%	0.11%	0.19%	0.15%	0.03%	0.04%	0.06%	0.08%	0.06%	0.22%
MON-SQOLIM	50	1.38%	1.22%	0.96%	0.49%	0.84%	0.65%	0.12%	0.19%	0.24%	0.36%	0.28%	0.95%
WSQOP	-50	5.25%	4.28%	3.93%	2.45%	3.17%	2.52%	0.61%	0.99%	0.76%	1.84%	2.39%	2.92%
WSQOP	-10	0.73%	0.58%	0.53%	0.31%	0.44%	0.35%	0.07%	0.12%	0.10%	0.25%	0.30%	0.40%
WSQOP	10	-0.73%	-0.58%	-0.53%	-0.30%	-0.44%	-0.35%	-0.06%	-0.12%	-0.10%	-0.25%	-0.30%	-0.40%
WSQOP	50	-2.90%	-2.28%	-2.03%	-1.13%	-1.72%	-1.38%	-0.23%	-0.45%	-0.38%	-0.97%	-1.12%	-1.57%

Table D-5. Percent Change in *E. coli* Geometric Mean concentrations for 2008-2012 at the outlet of Courthouse Creek

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly <i>E. coli</i> Geometric Mean											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FSTDEC	-50	2.95%	2.98%	3.83%	3.95%	5.49%	6.66%	6.14%	5.46%	3.69%	3.26%	2.47%	2.19%
FSTDEC	-10	0.58%	0.58%	0.74%	0.77%	1.05%	1.27%	1.17%	1.04%	0.71%	0.63%	0.48%	0.43%
FSTDEC	10	-0.57%	-0.58%	-0.73%	-0.76%	-1.03%	-1.24%	-1.15%	-1.03%	-0.70%	-0.63%	-0.48%	-0.42%
FSTDEC	50	-2.82%	-2.84%	-3.60%	-3.70%	-5.00%	-5.97%	-5.52%	-4.97%	-3.44%	-3.07%	-2.36%	-2.10%
MON-SQOLIM	-50	-2.77%	-2.74%	-2.37%	-1.37%	-1.93%	-1.54%	-0.39%	-0.51%	-0.59%	-1.00%	-0.89%	-1.88%
MON-SQOLIM	-10	-0.49%	-0.56%	-0.48%	-0.28%	-0.39%	-0.31%	-0.08%	-0.10%	-0.12%	-0.19%	-0.20%	-0.36%
MON-SQOLIM	10	0.57%	0.53%	0.46%	0.27%	0.38%	0.30%	0.08%	0.10%	0.11%	0.19%	0.19%	0.41%

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly <i>E. coli</i> Geometric Mean											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MON-SQOLIM	50	2.31%	2.33%	2.02%	1.26%	1.68%	1.35%	0.37%	0.46%	0.50%	0.87%	0.87%	1.69%
WSQOP	-50	7.16%	6.10%	5.84%	3.92%	4.74%	3.62%	1.28%	1.62%	1.33%	2.65%	3.60%	4.39%
WSQOP	-10	0.98%	0.83%	0.78%	0.50%	0.64%	0.49%	0.15%	0.20%	0.17%	0.35%	0.45%	0.58%
WSQOP	10	-0.97%	-0.82%	-0.76%	-0.48%	-0.63%	-0.49%	-0.14%	-0.19%	-0.16%	-0.35%	-0.45%	-0.58%
WSQOP	50	-3.81%	-3.21%	-2.95%	-1.81%	-2.46%	-1.90%	-0.50%	-0.73%	-0.63%	-1.37%	-1.68%	-2.25%

*Table D-6. Percent Change in E. coli Geometric Mean concentrations for 2008-2012 at the outlet of Dickey's Swamp*

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly <i>E. coli</i> Geometric Mean											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FSTDEC	-50	6.97%	6.11%	8.66%	7.20%	7.79%	10.20%	5.04%	6.11%	1.80%	4.01%	3.84%	3.73%
FSTDEC	-10	1.33%	1.16%	1.63%	1.35%	1.44%	1.86%	0.93%	1.13%	0.34%	0.76%	0.74%	0.72%
FSTDEC	10	-1.31%	-1.14%	-1.60%	-1.31%	-1.39%	-1.79%	-0.90%	-1.09%	-0.34%	-0.75%	-0.72%	-0.71%
FSTDEC	50	-6.33%	-5.50%	-7.63%	-6.24%	-6.50%	-8.29%	-4.23%	-5.09%	-1.62%	-3.61%	-3.51%	-3.43%
MON-SQOLIM	-50	-2.32%	-2.07%	-1.83%	-0.82%	-1.35%	-1.08%	-0.28%	-0.39%	-0.38%	-0.60%	-0.70%	-1.54%
MON-SQOLIM	-10	-0.39%	-0.35%	-0.31%	-0.14%	-0.23%	-0.19%	-0.05%	-0.07%	-0.06%	-0.10%	-0.13%	-0.26%
MON-SQOLIM	10	0.37%	0.34%	0.30%	0.14%	0.23%	0.18%	0.05%	0.07%	0.06%	0.10%	0.12%	0.26%
MON-SQOLIM	50	1.98%	1.85%	1.61%	0.79%	1.25%	1.02%	0.26%	0.37%	0.35%	0.57%	0.70%	1.42%
WSQOP	-50	10.29%	8.51%	8.29%	6.01%	5.66%	5.58%	2.13%	2.60%	1.70%	3.52%	5.43%	7.05%
WSQOP	-10	1.42%	1.17%	1.14%	0.79%	0.79%	0.75%	0.26%	0.34%	0.24%	0.47%	0.72%	0.95%
WSQOP	10	-1.34%	-1.09%	-1.07%	-0.72%	-0.75%	-0.70%	-0.23%	-0.31%	-0.22%	-0.44%	-0.67%	-0.88%
WSQOP	50	-5.33%	-4.33%	-4.26%	-2.79%	-3.00%	-2.78%	-0.85%	-1.21%	-0.89%	-1.74%	-2.61%	-3.50%

Table D-7. Percent Change in *E. coli* Geometric Mean concentrations for 2008-2012 at the outlet of Dogwood Fork

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly <i>E. coli</i> Geometric Mean											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FSTDEC	-50	0.28%	0.25%	0.20%	0.10%	0.26%	0.32%	0.01%	0.04%	0.05%	0.14%	0.05%	0.12%
FSTDEC	-10	0.05%	0.05%	0.04%	0.02%	0.05%	0.06%	0.00%	0.01%	0.01%	0.03%	0.01%	0.02%
FSTDEC	10	-0.05%	-0.05%	-0.04%	-0.02%	-0.05%	-0.06%	0.00%	-0.01%	-0.01%	-0.03%	-0.01%	-0.02%
FSTDEC	50	-0.27%	-0.24%	-0.20%	-0.09%	-0.25%	-0.31%	-0.01%	-0.04%	-0.05%	-0.14%	-0.05%	-0.12%
MON-SQOLIM	-50	-2.73%	-2.46%	-2.03%	-1.21%	-1.70%	-1.57%	-0.40%	-0.45%	-0.61%	-1.02%	-1.01%	-1.98%
MON-SQOLIM	-10	-0.48%	-0.45%	-0.38%	-0.24%	-0.31%	-0.29%	-0.08%	-0.09%	-0.12%	-0.19%	-0.19%	-0.36%
MON-SQOLIM	10	0.50%	0.47%	0.39%	0.24%	0.34%	0.31%	0.08%	0.09%	0.12%	0.20%	0.21%	0.39%
MON-SQOLIM	50	2.15%	2.00%	1.66%	1.07%	1.45%	1.35%	0.38%	0.41%	0.51%	0.88%	0.93%	1.69%
WSQOP	-50	6.36%	5.23%	4.84%	3.66%	3.91%	3.71%	1.37%	1.50%	1.37%	2.64%	3.60%	4.14%
WSQOP	-10	0.88%	0.72%	0.65%	0.47%	0.54%	0.51%	0.16%	0.19%	0.18%	0.36%	0.46%	0.55%
WSQOP	10	-0.86%	-0.70%	-0.63%	-0.45%	-0.53%	-0.50%	-0.15%	-0.18%	-0.17%	-0.35%	-0.44%	-0.53%
WSQOP	50	-3.42%	-2.76%	-2.45%	-1.71%	-2.07%	-1.95%	-0.54%	-0.68%	-0.65%	-1.39%	-1.67%	-2.10%

Table D-8. Percent Change in *E. coli* Geometric Mean concentrations for 2008-2012 at the outlet of Dorrell Creek

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly <i>E. coli</i> Geometric Mean											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FSTDEC	-50	3.81%	2.67%	2.85%	1.22%	2.36%	2.63%	0.21%	0.84%	0.42%	1.09%	0.97%	1.21%
FSTDEC	-10	0.73%	0.51%	0.55%	0.23%	0.44%	0.49%	0.04%	0.16%	0.08%	0.21%	0.19%	0.24%
FSTDEC	10	-0.73%	-0.51%	-0.54%	-0.23%	-0.43%	-0.48%	-0.04%	-0.15%	-0.08%	-0.21%	-0.19%	-0.23%
FSTDEC	50	-3.54%	-2.46%	-2.64%	-1.10%	-2.07%	-2.25%	-0.19%	-0.73%	-0.37%	-1.00%	-0.91%	-1.14%
MON-SQOLIM	-50	-3.69%	-3.06%	-3.05%	-1.33%	-2.05%	-1.74%	-0.38%	-0.57%	-0.57%	-0.98%	-1.07%	-2.05%
MON-SQOLIM	-10	-0.50%	-0.45%	-0.44%	-0.20%	-0.31%	-0.27%	-0.06%	-0.09%	-0.08%	-0.15%	-0.17%	-0.29%
MON-SQOLIM	10	0.48%	0.44%	0.45%	0.23%	0.30%	0.26%	0.06%	0.09%	0.09%	0.16%	0.16%	0.28%

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly <i>E. coli</i> Geometric Mean											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MON-SQOLIM	50	2.92%	2.47%	2.44%	1.21%	1.73%	1.49%	0.37%	0.52%	0.48%	0.86%	1.02%	1.82%
WSQOP	-50	8.07%	6.20%	6.36%	3.80%	4.39%	3.93%	1.23%	1.59%	1.13%	2.60%	3.64%	4.37%
WSQOP	-10	1.11%	0.84%	0.86%	0.47%	0.60%	0.53%	0.14%	0.20%	0.15%	0.34%	0.46%	0.58%
WSQOP	10	-1.09%	-0.81%	-0.84%	-0.44%	-0.58%	-0.51%	-0.13%	-0.19%	-0.14%	-0.33%	-0.44%	-0.57%
WSQOP	50	-4.31%	-3.18%	-3.28%	-1.66%	-2.27%	-2.00%	-0.46%	-0.72%	-0.56%	-1.29%	-1.66%	-2.22%

*Table D-9. Percent Change in E. coli Geometric Mean concentrations for 2008-2012 at the outlet of Garnetts Creek*

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly <i>E. coli</i> Geometric Mean											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FSTDEC	-50	5.84%	4.21%	6.56%	4.64%	4.78%	5.77%	2.17%	3.15%	1.19%	2.40%	2.63%	2.46%
FSTDEC	-10	1.12%	0.81%	1.24%	0.88%	0.89%	1.07%	0.40%	0.59%	0.23%	0.46%	0.51%	0.47%
FSTDEC	10	-1.10%	-0.79%	-1.22%	-0.85%	-0.87%	-1.03%	-0.39%	-0.57%	-0.22%	-0.45%	-0.50%	-0.47%
FSTDEC	50	-5.35%	-3.84%	-5.84%	-4.09%	-4.14%	-4.86%	-1.82%	-2.70%	-1.07%	-2.19%	-2.42%	-2.28%
MON-SQOLIM	-50	-3.21%	-2.70%	-2.63%	-1.35%	-1.97%	-1.61%	-0.39%	-0.55%	-0.50%	-0.96%	-1.16%	-2.07%
MON-SQOLIM	-10	-0.65%	-0.56%	-0.52%	-0.28%	-0.40%	-0.33%	-0.08%	-0.11%	-0.10%	-0.20%	-0.26%	-0.43%
MON-SQOLIM	10	0.63%	0.53%	0.50%	0.27%	0.39%	0.32%	0.08%	0.11%	0.10%	0.20%	0.25%	0.42%
MON-SQOLIM	50	2.63%	2.26%	2.11%	1.19%	1.65%	1.36%	0.36%	0.49%	0.43%	0.86%	1.11%	1.83%
WSQOP	-50	7.87%	6.42%	6.61%	4.62%	4.93%	4.00%	1.45%	1.87%	1.41%	3.04%	4.68%	4.83%
WSQOP	-10	1.10%	0.88%	0.90%	0.57%	0.68%	0.55%	0.17%	0.23%	0.18%	0.40%	0.59%	0.65%
WSQOP	10	-1.11%	-0.88%	-0.90%	-0.56%	-0.69%	-0.55%	-0.16%	-0.23%	-0.18%	-0.41%	-0.59%	-0.65%
WSQOP	50	-4.40%	-3.48%	-3.53%	-2.11%	-2.69%	-2.17%	-0.57%	-0.87%	-0.66%	-1.58%	-2.22%	-2.55%

Table D-10. Percent Change in *E. coli* Geometric Mean concentrations for 2008-2012 at the outlet of Gravel Run

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly <i>E. coli</i> Geometric Mean											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FSTDEC	-50	0.95%	0.80%	0.72%	0.26%	0.65%	0.69%	0.08%	0.17%	0.10%	0.32%	0.23%	0.35%
FSTDEC	-10	0.19%	0.16%	0.14%	0.05%	0.13%	0.13%	0.01%	0.03%	0.02%	0.06%	0.05%	0.07%
FSTDEC	10	-0.19%	-0.16%	-0.14%	-0.05%	-0.13%	-0.13%	-0.01%	-0.03%	-0.02%	-0.06%	-0.05%	-0.07%
FSTDEC	50	-0.92%	-0.77%	-0.69%	-0.25%	-0.61%	-0.65%	-0.07%	-0.16%	-0.09%	-0.31%	-0.23%	-0.34%
MON-SQOLIM	-50	-4.09%	-3.73%	-3.58%	-2.71%	-3.44%	-3.08%	-2.06%	-1.55%	-1.97%	-2.05%	-1.88%	-3.17%
MON-SQOLIM	-10	-0.75%	-0.69%	-0.66%	-0.52%	-0.65%	-0.58%	-0.38%	-0.28%	-0.36%	-0.39%	-0.37%	-0.62%
MON-SQOLIM	10	0.70%	0.65%	0.63%	0.49%	0.61%	0.55%	0.36%	0.26%	0.34%	0.37%	0.36%	0.59%
MON-SQOLIM	50	3.02%	2.98%	2.82%	2.26%	2.69%	2.42%	1.57%	1.14%	1.52%	1.68%	1.63%	2.58%
WSQOP	-50	9.38%	7.62%	7.76%	6.22%	5.48%	5.96%	3.36%	3.06%	2.35%	3.88%	5.28%	7.15%
WSQOP	-10	1.29%	1.05%	1.06%	0.85%	0.76%	0.81%	0.42%	0.41%	0.32%	0.52%	0.73%	0.96%
WSQOP	10	-1.22%	-0.99%	-0.99%	-0.78%	-0.72%	-0.76%	-0.38%	-0.37%	-0.30%	-0.49%	-0.67%	-0.90%
WSQOP	50	-4.84%	-3.93%	-3.92%	-3.09%	-2.86%	-2.97%	-1.47%	-1.44%	-1.18%	-1.97%	-2.66%	-3.52%

Table D-11. Percent Change in *E. coli* Geometric Mean concentrations for 2008-2012 at the outlet of Herring Creek

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly <i>E. coli</i> Geometric Mean											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FSTDEC	-50	1.16%	1.51%	1.90%	2.75%	3.89%	4.99%	5.75%	4.54%	3.50%	2.43%	1.72%	1.39%
FSTDEC	-10	0.23%	0.30%	0.37%	0.54%	0.75%	0.96%	1.10%	0.88%	0.68%	0.48%	0.34%	0.27%
FSTDEC	10	-0.23%	-0.30%	-0.37%	-0.53%	-0.74%	-0.95%	-1.08%	-0.86%	-0.67%	-0.47%	-0.34%	-0.27%
FSTDEC	50	-1.13%	-1.47%	-1.83%	-2.62%	-3.65%	-4.61%	-5.25%	-4.22%	-3.30%	-2.33%	-1.67%	-1.35%
MON-SQOLIM	-50	-2.26%	-1.74%	-1.65%	-0.90%	-1.31%	-1.38%	-0.27%	-0.31%	-0.44%	-0.74%	-0.58%	-1.08%
MON-SQOLIM	-10	-0.40%	-0.31%	-0.29%	-0.16%	-0.24%	-0.25%	-0.05%	-0.06%	-0.08%	-0.13%	-0.11%	-0.20%
MON-SQOLIM	10	0.39%	0.31%	0.29%	0.18%	0.23%	0.24%	0.05%	0.06%	0.08%	0.14%	0.11%	0.19%

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly <i>E. coli</i> Geometric Mean											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MON-SQOLIM	50	1.75%	1.42%	1.36%	0.81%	1.09%	1.18%	0.26%	0.29%	0.37%	0.64%	0.57%	0.95%
WSQOP	-50	5.72%	4.03%	4.05%	2.79%	3.01%	3.26%	1.01%	1.09%	1.12%	2.01%	2.40%	2.84%
WSQOP	-10	0.78%	0.55%	0.54%	0.36%	0.41%	0.44%	0.12%	0.14%	0.15%	0.27%	0.30%	0.37%
WSQOP	10	-0.77%	-0.53%	-0.53%	-0.34%	-0.40%	-0.43%	-0.11%	-0.13%	-0.14%	-0.26%	-0.29%	-0.36%
WSQOP	50	-3.04%	-2.09%	-2.04%	-1.29%	-1.58%	-1.69%	-0.39%	-0.49%	-0.55%	-1.02%	-1.11%	-1.40%

*Table D-12. Percent Change in E. coli Geometric Mean concentrations for 2008-2012 at the outlet of Market Swamp*

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly <i>E. coli</i> Geometric Mean											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FSTDEC	-50	1.91%	1.91%	2.15%	1.83%	2.72%	3.33%	2.22%	2.26%	1.14%	1.37%	1.15%	1.25%
FSTDEC	-10	0.37%	0.37%	0.42%	0.36%	0.52%	0.64%	0.43%	0.44%	0.22%	0.27%	0.23%	0.25%
FSTDEC	10	-0.37%	-0.37%	-0.41%	-0.35%	-0.51%	-0.63%	-0.42%	-0.43%	-0.22%	-0.27%	-0.22%	-0.24%
FSTDEC	50	-1.83%	-1.82%	-2.04%	-1.74%	-2.51%	-3.07%	-2.07%	-2.11%	-1.09%	-1.31%	-1.11%	-1.21%
MON-SQOLIM	-50	-1.02%	-0.88%	-0.76%	-0.38%	-0.61%	-0.47%	-0.17%	-0.17%	-0.18%	-0.29%	-0.30%	-0.70%
MON-SQOLIM	-10	-0.17%	-0.14%	-0.13%	-0.06%	-0.10%	-0.08%	-0.03%	-0.03%	-0.03%	-0.05%	-0.05%	-0.11%
MON-SQOLIM	10	0.16%	0.14%	0.12%	0.06%	0.10%	0.08%	0.03%	0.03%	0.03%	0.05%	0.05%	0.11%
MON-SQOLIM	50	0.93%	0.83%	0.71%	0.37%	0.59%	0.46%	0.17%	0.17%	0.18%	0.28%	0.30%	0.68%
WSQOP	-50	10.14%	8.12%	8.34%	5.86%	5.65%	5.62%	2.92%	3.10%	2.20%	3.62%	5.22%	7.34%
WSQOP	-10	1.40%	1.13%	1.16%	0.82%	0.80%	0.77%	0.37%	0.42%	0.31%	0.50%	0.73%	1.01%
WSQOP	10	-1.28%	-1.03%	-1.05%	-0.74%	-0.73%	-0.70%	-0.33%	-0.37%	-0.28%	-0.46%	-0.67%	-0.92%
WSQOP	50	-5.16%	-4.16%	-4.23%	-2.96%	-2.97%	-2.81%	-1.27%	-1.47%	-1.13%	-1.84%	-2.71%	-3.68%

Table D-13. Percent Change in *E. coli* Geometric Mean concentrations for 2008-2012 at the outlet of Mattaponi River

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly <i>E. coli</i> Geometric Mean											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FSTDEC	-50	1.57%	2.06%	2.81%	3.33%	4.09%	6.55%	3.27%	6.08%	0.84%	2.49%	2.07%	1.83%
FSTDEC	-10	0.31%	0.40%	0.55%	0.65%	0.79%	1.25%	0.63%	1.16%	0.16%	0.49%	0.40%	0.36%
FSTDEC	10	-0.31%	-0.40%	-0.54%	-0.64%	-0.78%	-1.22%	-0.61%	-1.14%	-0.16%	-0.48%	-0.40%	-0.36%
FSTDEC	50	-1.53%	-1.98%	-2.68%	-3.14%	-3.80%	-5.88%	-2.98%	-5.49%	-0.79%	-2.37%	-1.99%	-1.77%
MON-SQOLIM	-50	-1.63%	-1.36%	-1.28%	-0.53%	-0.74%	-0.92%	-0.26%	-0.31%	-0.35%	-0.59%	-0.37%	-1.01%
MON-SQOLIM	-10	-0.29%	-0.24%	-0.22%	-0.10%	-0.14%	-0.17%	-0.05%	-0.06%	-0.06%	-0.11%	-0.07%	-0.19%
MON-SQOLIM	10	0.28%	0.23%	0.21%	0.09%	0.13%	0.17%	0.05%	0.06%	0.06%	0.10%	0.07%	0.18%
MON-SQOLIM	50	1.30%	1.13%	1.08%	0.50%	0.65%	0.83%	0.24%	0.28%	0.29%	0.52%	0.37%	0.89%
WSQOP	-50	7.70%	6.28%	6.68%	5.59%	3.45%	5.26%	3.15%	3.56%	1.87%	3.49%	4.81%	6.52%
WSQOP	-10	1.11%	0.92%	0.98%	0.83%	0.51%	0.75%	0.42%	0.50%	0.26%	0.51%	0.72%	0.92%
WSQOP	10	-1.04%	-0.85%	-0.91%	-0.76%	-0.48%	-0.69%	-0.37%	-0.45%	-0.23%	-0.47%	-0.66%	-0.84%
WSQOP	50	-4.25%	-3.49%	-3.76%	-3.13%	-2.00%	-2.81%	-1.43%	-1.81%	-0.94%	-1.94%	-2.74%	-3.41%

Table D-14. Percent Change in *E. coli* Geometric Mean concentrations for 2008-2012 at the outlet of XDN-Garnetts Creek, UT

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly <i>E. coli</i> Geometric Mean											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FSTDEC	-50	0.31%	0.36%	0.42%	0.48%	0.74%	0.95%	0.92%	0.74%	0.58%	0.43%	0.29%	0.30%
FSTDEC	-10	0.06%	0.07%	0.08%	0.09%	0.14%	0.19%	0.18%	0.15%	0.11%	0.08%	0.06%	0.06%
FSTDEC	10	-0.06%	-0.07%	-0.08%	-0.09%	-0.14%	-0.18%	-0.18%	-0.14%	-0.11%	-0.08%	-0.06%	-0.06%
FSTDEC	50	-0.31%	-0.35%	-0.41%	-0.47%	-0.71%	-0.91%	-0.88%	-0.71%	-0.57%	-0.42%	-0.28%	-0.29%
MON-SQOLIM	-50	-4.27%	-3.83%	-3.26%	-2.13%	-2.65%	-2.35%	-0.89%	-0.86%	-0.89%	-1.59%	-1.62%	-3.23%
MON-SQOLIM	-10	-0.68%	-0.64%	-0.55%	-0.38%	-0.45%	-0.41%	-0.16%	-0.15%	-0.15%	-0.28%	-0.29%	-0.54%
MON-SQOLIM	10	0.74%	0.62%	0.53%	0.36%	0.43%	0.39%	0.16%	0.15%	0.15%	0.26%	0.28%	0.57%

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly <i>E. coli</i> Geometric Mean											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MON-SQOLIM	50	3.23%	3.07%	2.64%	1.89%	2.19%	1.99%	0.84%	0.78%	0.76%	1.36%	1.48%	2.69%
WSQOP	-50	8.26%	6.82%	6.49%	5.18%	5.05%	4.99%	2.42%	2.32%	1.82%	3.49%	4.61%	5.94%
WSQOP	-10	1.13%	0.93%	0.87%	0.67%	0.69%	0.67%	0.29%	0.30%	0.24%	0.46%	0.60%	0.79%
WSQOP	10	-1.11%	-0.91%	-0.84%	-0.64%	-0.67%	-0.65%	-0.27%	-0.28%	-0.23%	-0.45%	-0.57%	-0.77%
WSQOP	50	-4.36%	-3.58%	-3.28%	-2.46%	-2.64%	-2.52%	-1.01%	-1.07%	-0.90%	-1.79%	-2.19%	-2.97%

*Table D-15. Percent Change in E. coli Geometric Mean concentrations for 2008-2012 at the outlet of XJG-Dickeys Swamp, UT*

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly <i>E. coli</i> Geometric Mean											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FSTDEC	-50	0.22%	0.19%	0.14%	0.09%	0.20%	0.28%	0.03%	0.04%	0.05%	0.13%	0.05%	0.11%
FSTDEC	-10	0.04%	0.04%	0.03%	0.02%	0.04%	0.06%	0.01%	0.01%	0.01%	0.03%	0.01%	0.02%
FSTDEC	10	-0.04%	-0.04%	-0.03%	-0.02%	-0.04%	-0.06%	-0.01%	-0.01%	-0.01%	-0.03%	-0.01%	-0.02%
FSTDEC	50	-0.22%	-0.19%	-0.14%	-0.09%	-0.19%	-0.28%	-0.03%	-0.04%	-0.05%	-0.13%	-0.05%	-0.11%
MON-SQOLIM	-50	-1.83%	-1.50%	-1.05%	-0.61%	-1.01%	-0.93%	-0.16%	-0.21%	-0.36%	-0.60%	-0.46%	-1.14%
MON-SQOLIM	-10	-0.32%	-0.27%	-0.19%	-0.12%	-0.19%	-0.17%	-0.03%	-0.04%	-0.06%	-0.11%	-0.09%	-0.21%
MON-SQOLIM	10	0.31%	0.26%	0.19%	0.11%	0.18%	0.17%	0.03%	0.04%	0.06%	0.11%	0.09%	0.20%
MON-SQOLIM	50	1.46%	1.26%	0.91%	0.57%	0.89%	0.83%	0.16%	0.20%	0.31%	0.52%	0.43%	1.00%
WSQOP	-50	4.91%	3.76%	3.12%	2.24%	2.72%	2.68%	0.75%	0.88%	0.86%	1.70%	1.93%	2.90%
WSQOP	-10	0.67%	0.51%	0.41%	0.29%	0.37%	0.36%	0.09%	0.11%	0.12%	0.23%	0.25%	0.39%
WSQOP	10	-0.62%	-0.47%	-0.37%	-0.26%	-0.34%	-0.33%	-0.08%	-0.10%	-0.11%	-0.21%	-0.22%	-0.36%
WSQOP	50	-2.46%	-1.85%	-1.45%	-1.01%	-1.34%	-1.30%	-0.29%	-0.38%	-0.43%	-0.85%	-0.85%	-1.40%